June 1966

MATERIALS DATA HANDBOOK

Type 301 Stainless Steel

Edited by

John Sessler
Volker Weiss

Sponsored by

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama 35812

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SYRACUSE UNIVERSITY RESEARCH INSTITUTE
DEPARTMENT OF CHEMICAL ENGINEERING AND METALLURGY

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Contract No. NAS8-11345

DEPARTMENT OF CHEMICAL ENGINEERING AND METALLURGY
SYRACUSE UNIVERSITY, SYRACUSE, NEW YORK

PREFACE

This Materials Data Handbook on Type 301 stainless steel, was prepared by personnel and associates of the Department of Chemical Engineering and Metallurgy, Syracuse University, as part of a program sponsored by the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, Alabama.

It is intended that this Handbook present, in the form of a single document, a comprehensive summary of the materials property information presently available on the Type 301 alloy.

The scope of the information included herein includes physical and mechanical property data at cryogenic, ambient and elevated temperatures, supplemented with useful information in such areas as material procurement, metallurgy of the alloy, corrosion, environmental effects, fabrication and joining techniques. Design data are presented, where available, and these data are complemented with information on the typical behavior of the alloy. The major source for the design data used is the Department of Defense document, Military Handbook - 5.

The Handbook is divided into twelve (12) chapters as outlined below:

Chapter	1	General Information
	2	Procurement Information
	3	Metallurgy
	4	Production Practices
	5	Manufacturing Practices
	6	Space Environment Effects
	7	Static Mechanical Properties
	8	Dynamic and Time Dependant Properties
	9	Physical Properties
	10	Corrosion Resistance and Protection
	11	Surface Treatments
	12	Joining Techniques

Information on the alloy is given in the form of Tables and Illustrations supplemented with descriptive text where deemed useful by the authors. Source references for the information presented are listed at the end of each chapter.

ACKNOWLEDGEMENTS

The "Materials Data Handbook, Type 301 Stainless Steel", was prepared by Syracuse University under Contract No. NAS8-11345 for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The program was administered under the technical direction of the Propulsion and Vehicle Engineering Laboratory, Materials Division of the Space Flight Center with Mr. Melvin G. Olsen acting as project manager.

Acknowledgement is made to the following Syracuse University personnel and associates for their contributions to the program.

Technical Editors	Reproduction
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K. Schroder	B. Howden
B. A. Wasil	E. Kath

The editors are also appreciative of the cooperation extended to the program by members of the Mil-Hdbk-5 committee; personnel of the Defense Metals Information Center (DMIC), Battelle Memorial Institute; personnel of the NASA Marshall Space Flight Center; and to the many individuals and organizations (too numerous to mention) that have contributed to the generation of this document.

John G. Sessler, Editor
Volker Weiss, Associate Editor

* Associate Professor, Dept. of Metallurgical Engineering, Illinois Institute of Technology.

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TABULAR ABSTRACT

Type 301 Stainless Steel

TYPE:

Austenitic stainless steel

NOMINAL COMPOSITION:

Fe-17Cr-7Ni

AVAILABILITY:

Full commercial ranges of sizes and product forms are available in annealed, 1/4 hard, 1/2 hard, 3/4 hard, full hard and extra full hard conditions.

TYPICAL PHYSICAL PROPERTIES:

Density	7.91 gr/cm^3 at RT
Thermal Conductivity	0.032 cal/cm sec C (at 0° C)
Thermal Coef Expansion	16.9 x 10^{-6} in/in/C (20 to 100C)
Specific Heat	0.12 cal/gr cm (0 to 100C)
Electrical Resistivity	72 microhm-cm at RT

TYPICAL MECHANICAL PROPERTIES:

F_{tu}	110,000 psi (Annealed)
	125,000 psi (1/4 Hard)
	150,000 psi (1/2 Hard)
	185,000 psi (Full Hard)
F_{ty}	40,000 psi (Annealed)
	75,000 psi (1/4 Hard)
	110,000 psi (1/2 Hard)
	140,000 psi (Full Hard)
e(2 inch)	50 percent (Annealed)
	25 percent (1/4 Hard)
	15 percent (1/2 Hard)
	8 percent (Full Hard)
E (tension)	28 x 10^6 psi

FABRICATION CHARACTERISTICS:

Weldability	Excellent (fusion and resistance methods)
Formability	Good in annealed condition
Machinability	Good if proper tools and lubricants are employed

COMMENTS:

Alloy exhibits excellent corrosion and oxidation resistance and has good creep strength at elevated temperatures. High strengths are developed by cold working.

SYMBOLS

a	One-half notch section dimension
A	Area of cross section; "A" basis for mechanical property values (Mil-Hdbk-5)
Å	Angstrom unit
AC	Air cool
AMS	Aerospace Material Specifications
Ann	Annealed
AUS	Austenitize
Av or Avg	Average
B	"B" basis for mechanical property values (Mil-Hdbk-5)
b	Subscript "bending"
bcc	Body centered cubic
BHN	Brinell hardness number
br	Subscript "bearing"
Btu	British thermal unit (s)
C	Degress (s) Centigrade
c	Subscript "compression"
CD	Cold drawn
CF	Cold finished
cm	Centimeter
c_p	Specific heat
CR	Cold rolled
CW	Cold worked
CVM	Consumable vacuum melted
D or Dia	Diameter
DPH	Diamond pyramid hardness
e	Elongation in percent
E	Modulus of elasticity, tension
E_c	Modulus of elasticity, compression
e/D	Ratio of edge distance to hole diameter
E_s	Secant modulus
E_t	Tangent modulus
ev	Electron volt (s)

F	Degree (s) Fahrenheit
f	Subscript "fatigue"
F_{bru}	Bearing ultimate strength
F_{bry}	Bearing yield strength
fcc	Face centered cubic
FC	Furnace cool
F_{cy}	Compressive yield stress
F_{su}	Shear stress; shear strength
F_{tu}	Tensile ultimate strength
F_{ty}	0.2% tensile yield strength (unless otherwise indicated)
G	Modulus of rigidity
HAZ	Heat affected zone in weldments
hcp	Hexagonal close pack
hr	hour (s)
HT	Heat treat
IACS	International annealed copper standards
in	inch
ipm	inches per minute
K	Stress intensity factor; thermal conductivity
K_c	Measure of fracture toughness (plane stress) at point of crack growth instability
K_{Ic}	Plane strain fracture toughness value
KSI or ksi	Thousand pounds per square inch
K_t	Theoretical elastic stress concentration factor
L	Longitudinal
lb	Pound
LT	Long transverse (same as transverse)
M	Bending moment
m	Subscript "mean"
Max	Maximum
MIL	Military
Min	Minimum
N	Cycles to failure
NSR	Notch strength ratio
NTS	Notch tensile strength

OQ	Oil quench
ppm	Parts per million
pt	Point
r	radius
RA	Reduction in area; Rockwell hardness A scale
RB	Rockwell hardness B scale
RC	Rockwell hardness C scale
ρ (rho)	Density
rpm	Revolutions per minute
RT	Room temperature
SA	Solution anneal
sec	second
S-N	S = stress; N = number of cycles
Spec	Specifications; specimen
ST	Solution treat; short transverse
T	Transverse
t	Thickness; Time, hour
Temp	Temperature
typ	Typical
Var	Variable
VHN	Vickers' hardness number
W	Width
WQ	Water quench

CHAPTER 1

GENERAL INFORMATION

1.1 Type 301 is the lowest alloyed member of the versatile 18 percent chromium, 8 percent nickel series of steels. More generally, it belongs to the larger family of austenitic stainless steels. The austenitic iron-chromium-nickel alloys were developed in the Krupp Laboratories by Benno Strauss and Edward Maurer in Germany during the years 1909-1912. Strauss and others, in later work, developed steels which ultimately led to the 18-8 series of stainless steels. These steels are widely used today, (Ref. 1.1, p. 1313).

1.2 The austenitic stainless steels were developed in the search for materials to be used in pyrometer tubes. These steels, while developed as corrosion-resistant alloys, also possess excellent oxidation resistance as well as good creep strength at elevated temperatures and good cold formability, (Ref. 1.2).

1.3 Of the austenitic stainless steels, Type 301 is one of the most frequently used at high strength levels in aircraft and missiles because of its greater work-hardening characteristics, (Ref. 1.2). Also because of its high strength properties, Type 301 is used in the construction of bus, truck trailer and railroad car bodies. It is used for automobile wheel discs, architectural trim, flashing and roof drainage products, (Ref. 1.5).

1.4 The alloy cannot be hardened by heat treatment. However, the alloy hardens rapidly by cold working. It is possible to raise tensile strengths as high as 275 ksi at room temperature. Wrought Type 301 is ordinarily used in either the annealed or cold rolled condition. In the annealed condition the mechanical properties are those of substantially stress-free austenite. Generally, the tensile strength will be between 85 and 110 ksi with high ductility, comparatively low yield strength, high resistance to impact, relative insensitivity to notch effects, and low resistance to forming. Cold working increases hardness, strength and elastic properties but consequently reduces ductility and makes forming operations more difficult. The degrees of these effects will depend upon the amount of cold work that has been applied, (Ref. 1.3).

1.5 Type 302 stainless steel has a slightly higher alloying composition than Type 301. Many of the specifications for Type 302 have a close enough range of composition for chromium and nickel to include Type 301 in its lower range. The properties of Type 301 and 302 are only slightly different; while 302 is slightly inferior to 301 in strength it has a better corrosion resistance, (Ref. 1.4).

1.6 General Precautions

1.61 Type 301 should not be used at temperatures of 750 to 1650F and should not be cooled slowly from higher temperatures through this range when severe corrosive conditions are anticipated. Exposure to 900F or above reduces strength due to recrystallization, (Ref. 1.2).

CHAPTER 1 - REFERENCES

1.1 J. M. Camp and C. B. Francis, "The Making, Shaping and Treating of Steel", 6th Edition, United States Steel Co., (1951)

1.2 MIL-HDBK-5, "Metallic Materials and Elements for Flight Vehicle Structures", Department of Defense, (August 1962)

1.3 The International Nickel Co., "Heat Treatment and Physical Properties of the Chromium-Nickel Stainless Steels", Nickel Alloy Steels Section 7, Data Sheet A, (1947)

1.4 V. Weiss and J. G. Sessler, (Editors), "Aerospace Structural Metals Handbook", 2nd Revision, Syracuse University Press, (1965)

1.5 Republic Steel Corp., "Republic Enduro Stainless Steel", (1946)

CHAPTER 2

PROCUREMENT INFORMATION

2.1 General. Type 301 is available in the full commercial range of sizes for sheet, strip, plate, wire, bar and rod, (Ref. 2.1).

2.2 Procurement Specifications. AMS specifications that apply specifically to Type 301 as of February 15, 1965 and equivalent Military and ASTM Specifications are listed in Table 2.2.

2.3 Comparison of Specifications. The three AMS specifications and ASTM A-177-58 are specifically for Type 301 stainless steel. The other ASTM specification A-67-63 and all the Federal and Military specifications are for a general classification of corrosion-resistant steels or chromium-nickel steels or sometimes more specifically the classification of 18-8 steels. For sheet and strip the maximum mechanical properties for the various degrees of cold working correspond with AMS, ASTM and Military specifications.

2.4 Major Producers of the Alloy. Practically all alloy and stainless steel mills make this alloy under their own proprietary name or under AISI Type 301 specifications. Representative producers of Type 301 steel are listed below:

USS 301 -	United States Steel Corporation, Pittsburgh, Pa.
Allegheny Metal 17-7, Type 301	Allegheny Ludlum Steel Corp., Pittsburgh 22, Pa.
Carpenter Stainless No. 301	The Carpenter Steel Co., Reading, Pa.
Crucible 301 Stainless Steel	Crucible Steel Company of America, Pittsburgh 30, Pa.
Jessop Type 301	Jessop Steel Co., Washington, Pa.
Stainless Steel Type 301	Universal-Cyclops Steel Corp., Bridgeville, Pa.
Enduro Type 301	Republic Steel Corp., Cleveland, Ohio 44101

2.5 Available Forms, Sizes and Conditions. Type 301 is available in the full commercial range of sizes and forms in annealed, 1/4 hard, 1/2 hard, 3/4 hard, full hard and extra full hard condition.

PROCUREMENT SPECIFICATIONS (a)

TABLE 2.2

Source	Refs. 2.2, 2.3, 2.4			
Product	Condition	AMS	ASTM	Military
Plate, sheet and strip	Annealed	-	A167-63	-
Sheet and strip	CR-125 ksi, 1/4H	5517D	A177-58	MIL-S-5059
Sheet and strip	CR-150 ksi, 1/2H	5518C	A177-58	MIL-S-5059
Sheet and strip	CR-175 ksi, 3/4H	-	A177-58	MIL-S-5059
Sheet and strip	CR-185 ksi, FH	5519E	A177-58	MIL-S-5059

(a) As of February 15, 1965.

CHAPTER 2 - REFERENCES

2.1 "Alloy Digest, AISI Type 301", Filing Code SS-54, Stainless Steel, Engineering Alloy Digest, (April 1957)

2.2 Society of Automotive Engineergs, Inc., "SAE Aerospace Material Specifications", (February 15, 1965)

2.3 "1965 Book of ASTM Standards, Part 3, Wrought Iron Bar and Sheet, Metallic Coated Products", ASTM, (1965)

2.4 "Index of Specifications and Standards", Department of Defense, Part I, Alphabetical Listing, Part II, Numberical Listing, (September 1964) Supplemented (March 31, 1965)

CHAPTER 3

METALLURGY

3.1 Chemical Composition

3.11 The nominal chemical composition of Type 301 is:

Cr	17%
Ni	7%
Fe	Balance

3.12 There are some differences in the chemical composition ranges as listed by AMS and the steel producers. The chemical composition limits as specified by AMS and AISI are shown in Table 3.1.

3.13 The principal alloying elements are chromium and nickel. Equilibrium diagrams for the iron-chromium system are shown in Fig. 3.1.

Fig. 3.2 illustrates the iron-chromium-nickel diagram at 18% chromium content. Fig. 3.3 shows the iron-chromium-nickel diagram at 8% nickel content. The iron-chromium-nickel isothermal diagram at 1200F is presented in Fig. 3.4.

The chromium content gives the steel its passivity and resistance to oxidizing effects. The nickel content supplements the chromium in its resistance to oxidation to provide passivity where the chromium alone would not be sufficient for some corrodents. An increase in the chromium-nickel content improves the corrosion resistance properties of the steel, (Ref. 3.4). The mechanical properties of cold worked Type 301 are influenced by its chemical composition. Not only do the individual percentages have an effect upon the mechanical properties but also the ratios in which the elements are present in the steel influences its response to cold working.

As the nickel content is increased, the steel becomes more stable and the rate of strengthening by cold working will decrease. The effect of the chromium depends on the nickel and carbon contents. When the nickel is present in amounts greater than 9%, an increase of chromium will increase the rate of work hardening. However, if the nickel content is less than 7% an increase in chromium from 17% to 20% decreases the rate of work hardening.

Manganese and carbon also promote the stability of austenite. The carbon is very effective in this respect, while the manganese is much less effective than nickel, (Ref. 3.5).

3.2 Strengthening Mechanisms

3.21 General. Austenitic chromium-nickel stainless steels cannot be hardened by heat-treatment. Heat treatments are used, however, for purposes other than hardening. Full annealing maintains in the steel a fully austenitic structure, (see Fig. 3.5) and in this condition the steel will be at its softest and most malleable state. Lower heat treating temperatures may be employed to provide stress-relieving treatments or to improve yield strengths. Heat treatment may also be used to control carbide precipitation, (Ref. 3.5).

The austenite in Type 301 is not thermodynamically stable at room temperature. When the alloy is deformed plastically at or below room temperature the metastable austenite undergoes a partial transformation to martensite, (Ref. 3.5).

3.22 Annealing. The alloy should be annealed at 1950 to 2050F, one hour per inch of thickness.. Rapid cooling by a water quench should cool to 800F within 3 minutes as a maximum, (Ref. 3.6).

3.23 Stress-relief. To improve the elastic characteristics and to increase the compressive yield strength of cold worked conditions, heat to 400 to 800F, 8 to 36 hours maximum. In order to prevent stress cracking; full anneal or heat to 600F, 30 minutes to 2 hours after forming. Full anneal is mandatory where alloy is used in certain corrosive media, such as hot chloride which may lead to stress corrosion cracking, (Ref. 3.6).

3.24 Surface oxide scale formed during thermal treatment must be removed from all material which has to serve in a corrosive environment, (see Chapter 11, Surface Treatment).

3.25 Cold Working. The strength of sheet obtained by cold rolling depends largely upon the chemical composition, particularly the nickel and carbon contents. Fig. 3.6 shows the effect of rolling reduction and composition on tensile properties of the alloy. Table 3.2 shows percentage cold reduction and corresponding tensile strength for various tempers of the alloy.

3.3 Critical Temperatures. The melting range of the alloy is 2550 to 2650F. Carbon precipitation will take place when the alloy is exposed for a period of time to temperatures in the range of about 800F to about 1650F. The precipitation will take place during slow cooling or heating through this range or while holding at temperatures within the range. The amount of carbide that will precipitate will depend upon the carbon content, time and temperature and to some extent upon the chromium and nickel content. The carbides that precipitate in the grain boundaries are chromium rich, reducing the chromium content in the grains adjacent to the boundaries. Due to this depletion of chromium, the alloy becomes susceptible to corrosion. Heating the alloy to the annealing temperature will put the carbides into solution and rapid cooling through the critical range will keep the carbides in solution. Thus various fabricated parts or welded pieces that are subject to local heating, which may result in the precipitation of carbides, will require re-annealing in order to prevent subsequent corrosion, (Ref. 3.5).

The effect of carbon on the constitution of stainless steel containing 18% chromium and 8% nickel is shown in Fig. 3.7.

3.4 Crystal Structure. The fully annealed alloy is face-centered-cubic having a lattice constant of 3.56 Å, (Ref. 3.8).

3.5 Microstructure. The microstructure of the fully austenitic steel is shown in Fig. 3.8. Fig. 3.9 shows electron micrographs of material plastically deformed at temperatures of 10C and minus 188C. The percentage of martensite obtained is shown to be related to the degree of working and to the temperature.

Fig. 3.10 shows carbide precipitation at grain boundaries for the alloy reheated to 1112F after full annealing.

3.6 Metallographic Procedures. The specimens used for optical microscopy must be carefully polished, properly etched and observed accurately at required magnifications. The choice of polishing methods, whether mechanical or electrolytic depends upon the experience of the metallographer. While some metallographers have produced excellent results by mechanical polishing, it is believed by others that the polishing creates distortions causing slight changes in the properties of the surface. Also chips, as well as abrasive particles, tend to collect on the surface and form material loosely adherent to the surface.

Electrolytic polishing eliminates these difficulties and in general is excellent for homogeneous alloys. However, where massive particles of microconstituent exist, this method leads to unsatisfactory relief effects. Mechanical polishing is ordinarily done wet on turn tables covered with a polishing cloth of velvet or silk sprinkled with a polishing abrasive such as the aluminum or magnesium oxides of 500 to 600 mesh grade or diamond dust. Electrolytic polishing is accomplished by using the ground specimen as an anode of a d-c cell, using a proper cathode and an appropriate electrolytic solution. Conditions are best when a change in applied voltage produces no appreciable effect upon current density, (Ref. 3.11). Electropolishing information for austenitic stainless steel is shown in Table 3.3.

Etching is performed on specimens in order to distinguish between the constituents of the metal. Various etching agents are used to best bring out the particular phase under examination. Etching may be accomplished by immersion, swabbing or electrolytically. Table 3.4 gives etching agent and use for austenitic stainless steels.

CHEMICAL COMPOSITION RANGE

TABLE 3.1

Source	AMS		AISI	
Alloy	Type 301			
Ref.	3.1		3.2	
	Percent		Percent	
	Min	Max	Min	Max
Carbon	-	0.15	-	0.15
Chromium	17.00	-	16.00	18.00
Copper	-	0.50	-	-
Manganese	-	2.00	-	2.00
Molybdenum	-	0.50	-	-
Nickel	7.00	-	6.00	8.00
Phosphorus	-	0.040	-	0.045
Silicon	-	1.00	-	1.00
Sulfur	-	0.030	-	0.030
Iron	Balance		Balance	

PERCENTAGE COLD REDUCTION AND CORRESPONDING TENSILE STRENGTH FOR VARIOUS TEMPERS

TABLE 3.2

Source	(Ref. 3.6)	
Alloy	Type 301	
Temper	Percent cold reduction range	F_{tu} - range - ksi
1/4 hard	7-11	125-155
1/2 hard	18-21	150-180
3/4 hard	29-32	175-195
Full hard	40	190-220
Extra full hard	65	240-275

ELECTROPOLISHING OF AUSTENITIC STAINLESS STEEL

TABLE 3.3

Source		(Ref. 3.11)				
Alloy		Type 301				
Electrolyte		Cathode	Current density (amp/ft^2)	Voltage (volts)	Max temp (F)	Time (min)
Perchloric acid Acetic anhydride	30ml 60ml	Iron or aluminum	55	50*	85	4-5
HNO_3 Alcohol (methyl)	30ml 60ml	Any metal not attacked by electrolyte	-	-	-	-
Perchloric acid Glacial acetic acid	5ml 100ml		135-171	45	75	3-4
H_2O Orthophosphoric Glycerol	7ml 37ml 56ml		720	-	212-248	5-10

* Externally applied

ETCHING AGENT AND USE

TABLE 3.4

Source	(Ref. 3.11)		
Alloy	Type 301		
Etching Method	Etching Agent		Use
Immersion	$FeCl_3$ HCl (conc.) H_2O	5g 50ml 100ml	Grain structure
	Aqua Regia: HNO_3 (conc.) HCl (conc.)	 40ml 120ml	
	HNO_3 (conc.) HCl (conc.) Glycerin	40ml 120ml 160ml	
	Alcoholic; Orthonitrophenol HCl (50%) $(NH_4)_2SO_4$ (15%)	 20ml 40ml 40ml	
	Murakami's (dilute): $K_3Fe(CN)_6$ KOH H_2O	 10g 10g 100ml	Sigma phase and carbide precipitation
	Murakami's (conc.): $K_3Fe(CN)_6$ KOH H_2O	 30g 30g 60ml	
	Vilella's: HNO_3 (conc.) HCl (conc.) Glycerin	 15ml 30ml 45ml	
	NaOH $KMnO_4$ H_2O	1g 4g 100ml	
	Picric acid HCl Alcohol (methyl)	5g 5ml 90ml	

ETCHING AGENT AND USE

TABLE 3.4 (con'd)

Source	(Ref. 3.11)		
Alloy	Type 301		
Etching Method	Etching Agent		Use
Electrolytic	HCl (conc.) Alcohol (ethyl) 6v, 0.75 amp. - 30 sec.	10ml 90ml	Grain structure
	Glacial acetic acid HNO_3 (conc.) 1 amp. 10 sec. plus	20ml 40ml	
	Oxalic acid H_2O 1 amp. 10-15 sec.	10g 100ml	
	$HClO_4$ (70-72% acid) H_2O 1 amp. - 2 min.	10ml 90ml	
	CrO_3 H_2O 1 amp. - 1 min.	10g 100ml	
	CrO_3 H_2O 6v - 0.75 amp. - 1 min	10g 100ml	Sigma phase and carbide precipitation
	NaCN H_2O 1 amp. - 5-10 sec.	10g 100ml	Carbide precipitation
	NaCN H_2O 1 amp. 15 sec. - 2 min	10g 100ml	Sigma phase
	Oxalic acid H_2O 6v-0.75 amp.	10g 100ml	Sigma phase 1st followed by carbide precipitation

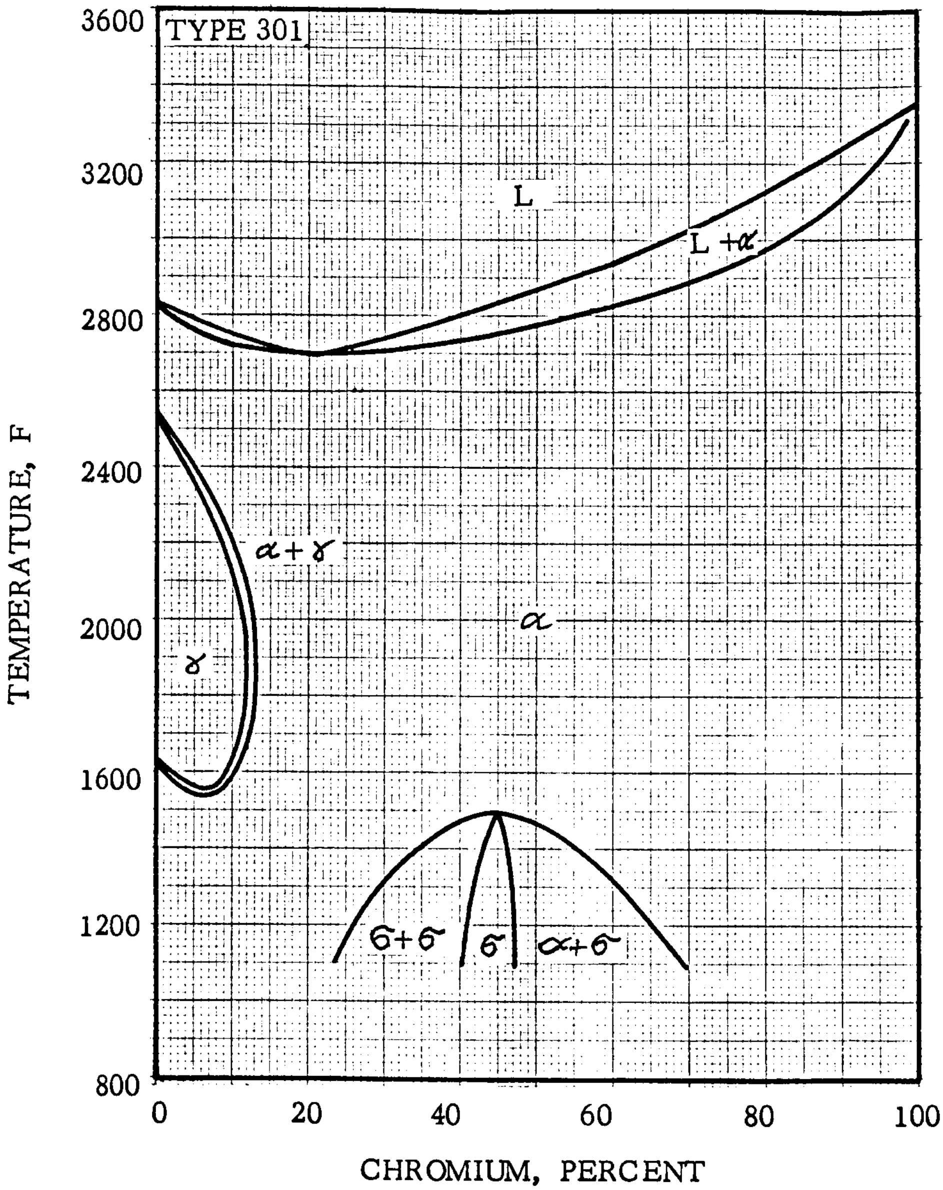


FIG. 3.1 IRON-CHROMIUM EQUILIBRIUM DIAGRAM

(Ref. 3.2)

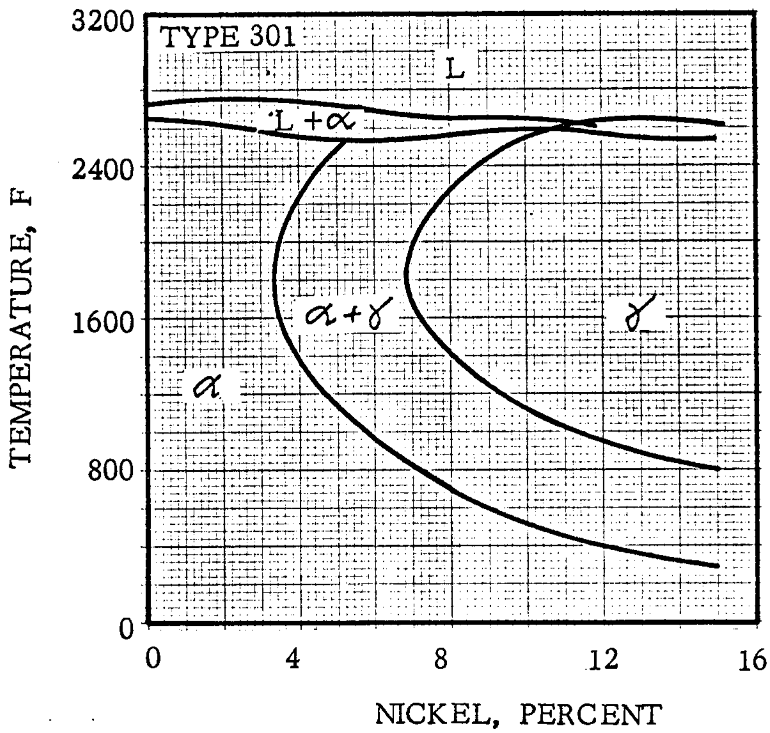


FIG. 3.2 IRON-CHROMIUM-NICKEL EQUILIBRIUM DIAGRAM AT CONSTANT CHROMIUM CONTENT OF 18 PERCENT

(Ref. 3.3)

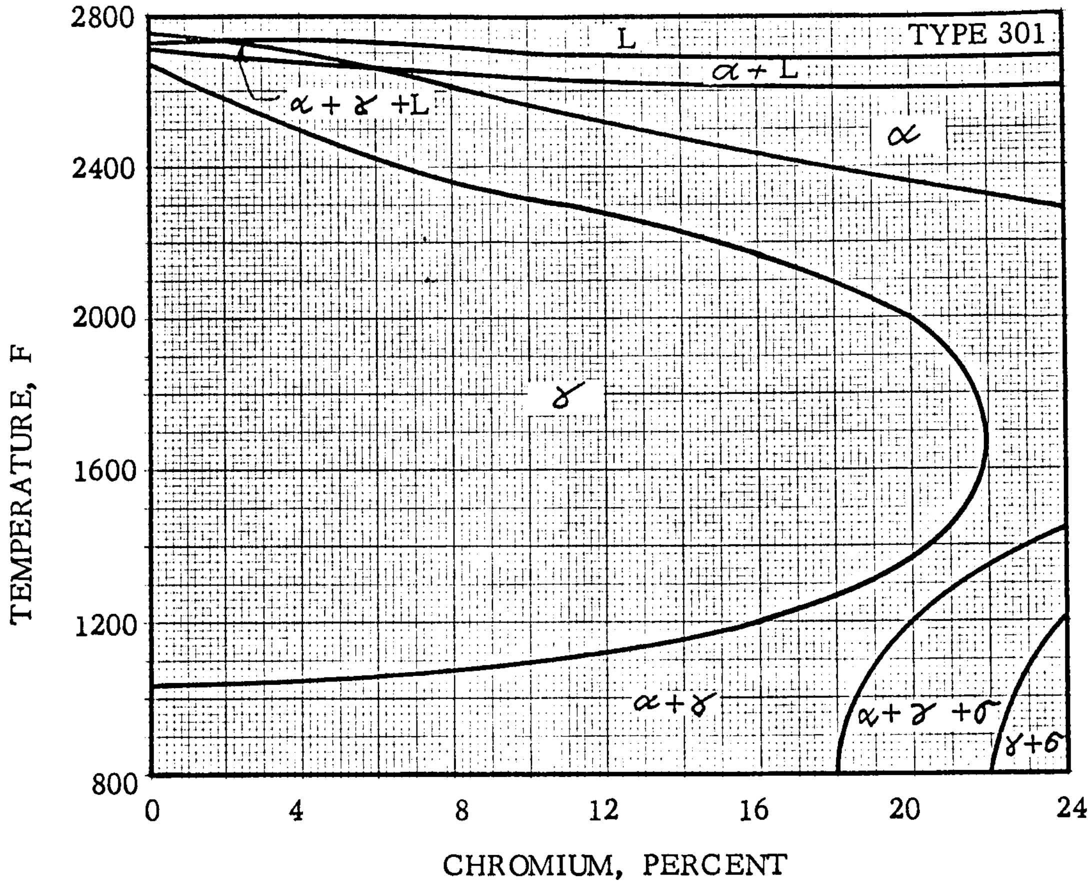


FIG. 3.3 IRON-CHROMIUM-NICKEL EQUILIBRIUM DIAGRAM AT CONSTANT NICKEL CONTENT OF 8%

(Ref. 3.3)

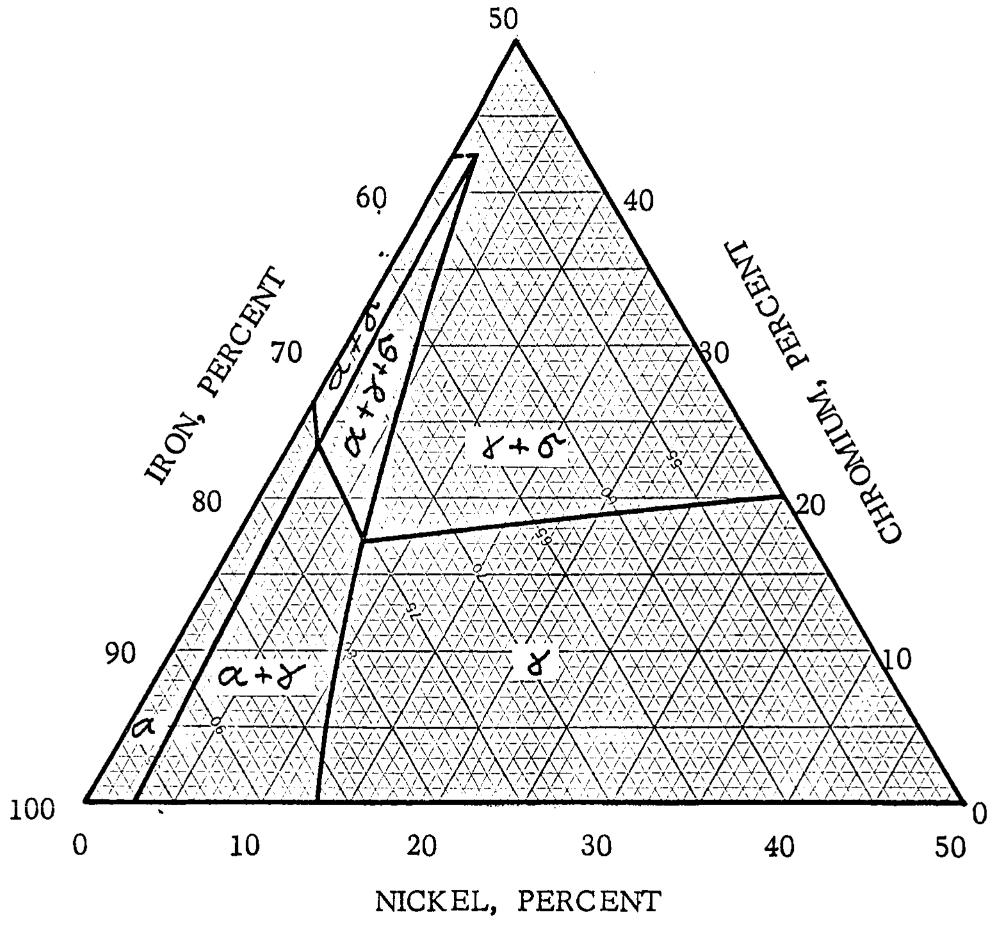


FIG. 3.4 IRON-CHROMIUM-NICKEL EQUILIBRIUM DIAGRAM AT 1200F

(Ref. 3.2)

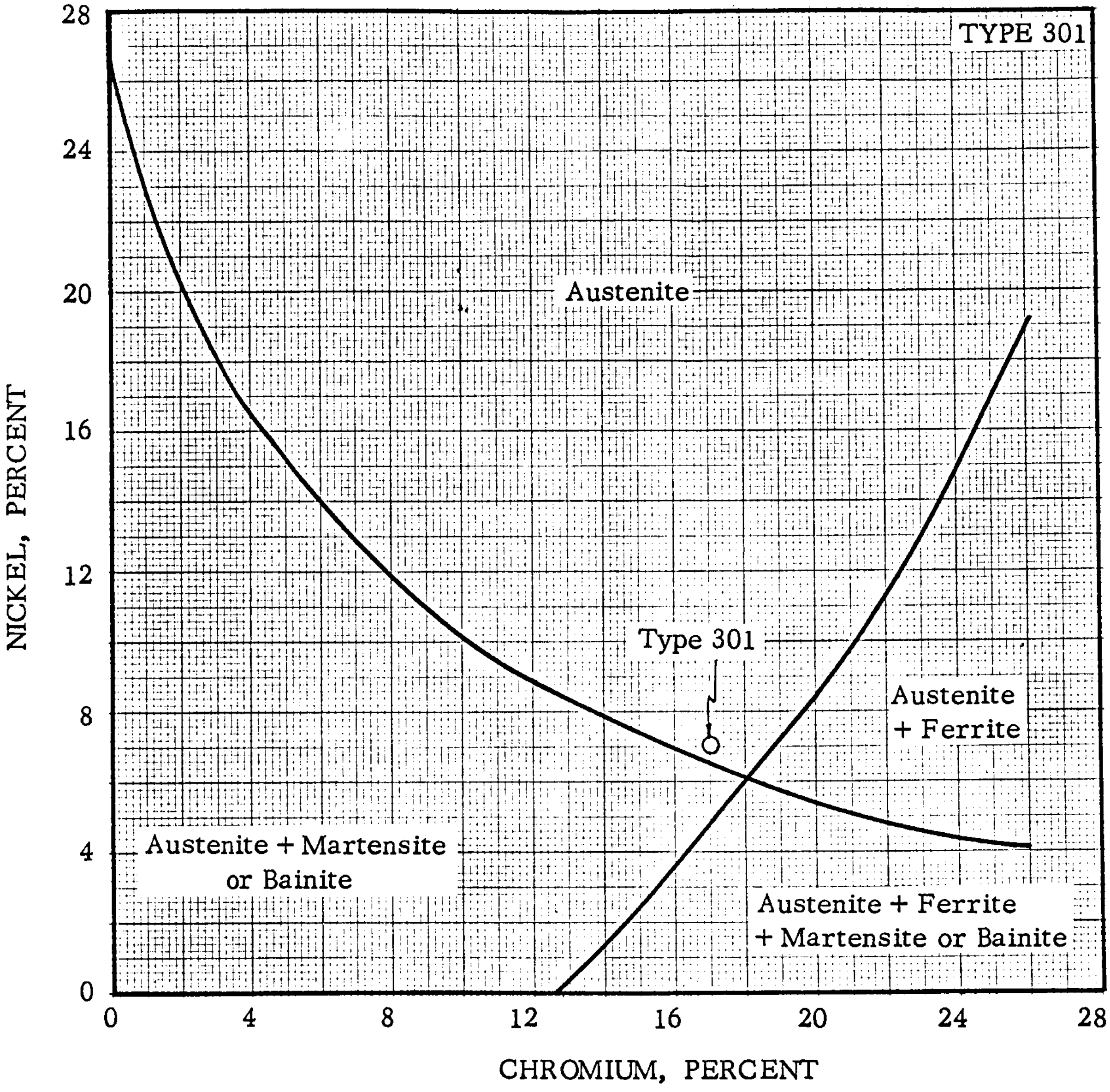


FIG. 3.5 EFFECT OF VARIATIONS IN CHROMIUM AND NICKEL IN QUENCHED-ANNEALED ALLOY CONTAINING 0.10C, 0.40Mn and 0.30Si

(Ref. 3.7)

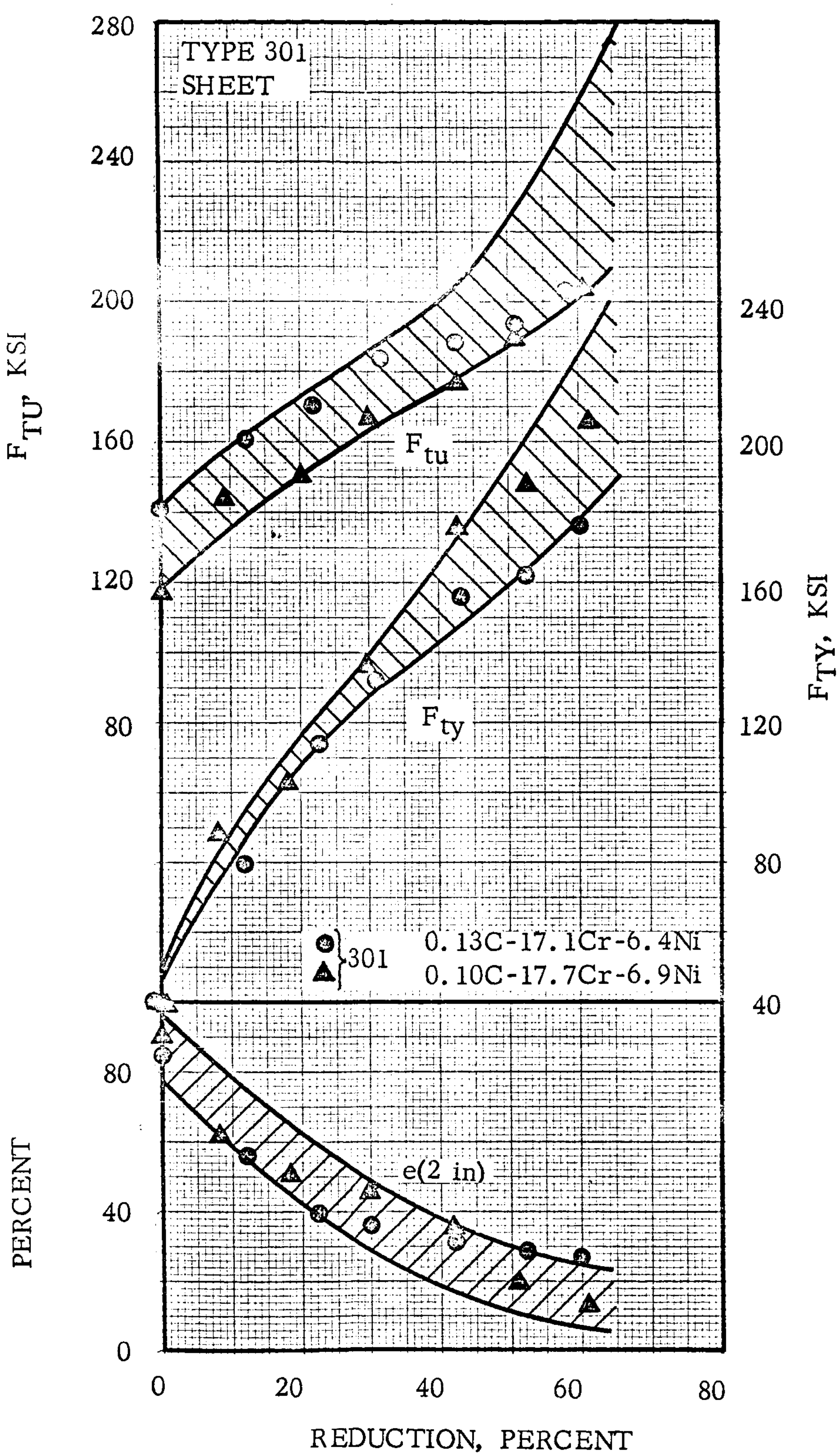


FIG. 3.6 EFFECT OF ROLLING REDUCTION AND COMPOSITION ON TENSILE PROPERTIES OF 300 SERIES STEELS

(Ref. 3.12)

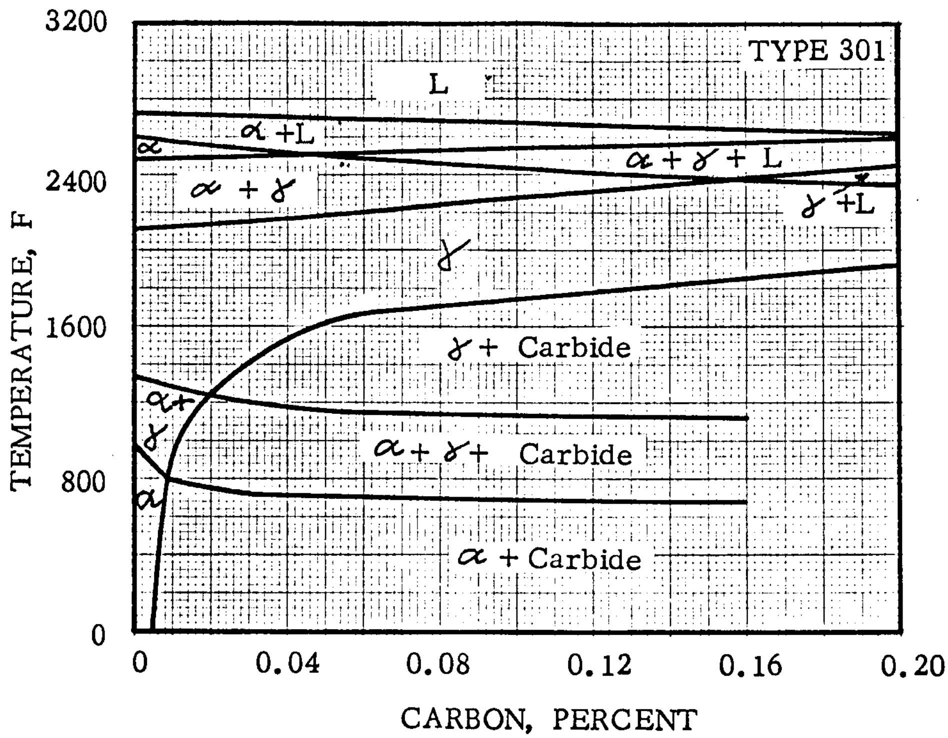
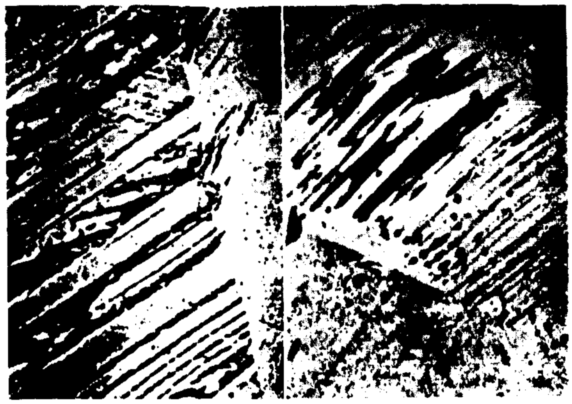


FIG. 3.7 EFFECT OF CARBON ON THE CONSTITUTION OF STAINLESS STEEL CONTAINING 18% CHROMIUM AND 8% NICKEL

(Ref. 3.3)

FIG. 3.8 18% CHROMIUM 8% NICKEL STEEL, WATER-QUENCHED FROM 1050°C. (x 100)

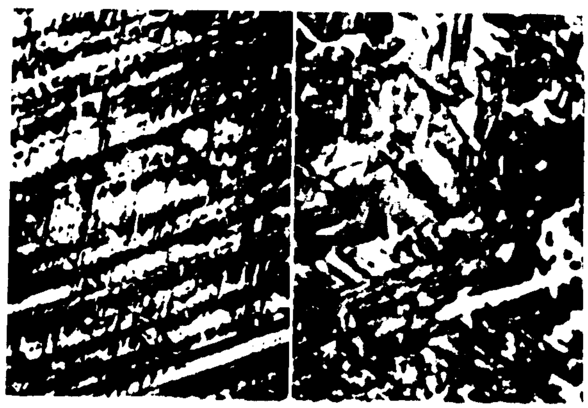
(Ref. 3.9)



(a) X 5000 (b) X 12,000

FIG. 3.9 (a) ELECTRON MICROGRAPHS OF AN 18/8 STAINLESS STEEL, DEFORMED IN TENSION TO A TRUE STRAIN OF 0.23 AT 10°C., GIVING 16% OF MARTENSITE

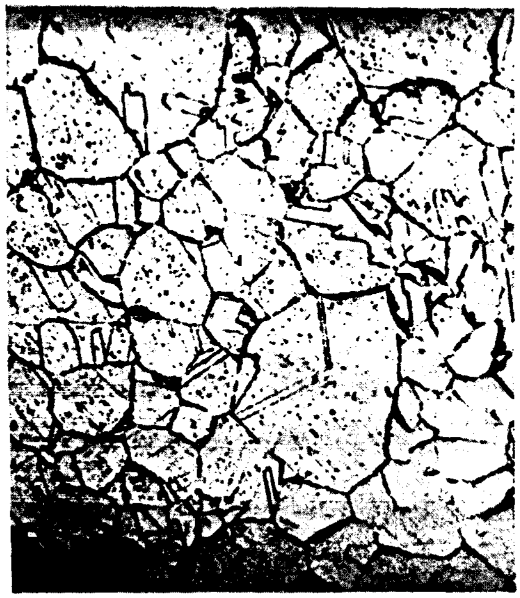
(Ref. 3.10)



(a) X 7800 (b) X 12,000

FIG. 3.9 (b) ELECTRON MICROGRAPHS OF AN 18/8 STAINLESS STEEL DEFORMED IN TENSION TO A TRUE STRAIN OF 0.144 at -188°C., GIVING 62% OF MARTENSITE

(Ref. 3.10)



(a) 18% CHROMIUM 8% NICKEL STEEL REHEATED AT 600°C. AFTER QUENCHING FROM 1050°C. (x 100)

(b) CARBIDE PRECIPITATION AT GRAIN BOUNDARIES (x 3000)

FIG. 3.10 MICROGRAPH OF ALLOY REHEATED TO 1112F AFTER QUENCHING FROM 1922F

(Ref. 3.9)

CHAPTER 3 - REFERENCES

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3.3 J. M. Camp and C. B. Francis, "The Making, Shaping and Treating of Steel", 6th Edition, United States Steel Company, (1951)

3.4 The International Nickel Co., "Corrosion Resisting Properties of the Chromium-Nickel Stainless Steels", Nickel Alloy Steels, Section 7, Data Sheet B, (1949)

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3.6 V. Weiss and J. G. Sessler, (Editors), "Aerospace Structural Metals Handbook", 2nd Rev., Syracuse University Press, (March 1965)

3.7 D. K. Bullens, "Steel and its Heat Treatment - Vol. III", 5th Edition, John Wiley & Son, (1949)

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3.9 F. H. Keating, "Chromium-Nickel Austenitic Steels", Butterworths Scientific Publication, (1956)

3.10 T. Angel, "Formation of Martensite in Austenitic Stainless Steels", <u>Journal of the Iron and Steel Institute</u>, Vol. 177, pp. 165-174, (1954)

3.11 J. P. Vidosic, "Study of Phase Identifications in Steel and Aluminum Alloys", Georgia Institute of Technology, Final Report, Project No. A-641 for NASA, (September 1963)

3.12 Allegheny-Ludlum Steel Corp., "High Strength Cold-Rolled Stainless Steels", Data Sheet (1958)

CHAPTER 4

PRODUCTION PRACTICES

4.1 General. All austenitic stainless steels are produced by melting in either the electric-arc or high frequency induction furnaces. In each case a cold charge is used. The necessity to maintain a low carbon content is aggravated by the high affinity for carbon and oxygen in the large quantity of chromium present in this class of steel. This is a special problem in the production of stainless steels. The composition of the charge, in normal steel production, has an excess of carbon, silicon and manganese. The melt is then refined by controlling the oxidation of the carbon, silicon and manganese by reaction with oxygen that comes from the furnace gases and from the oxides of iron from the added iron ore or millscale. During the refining operation the oxides (iron, silicon and manganese) are removed in the slag and carbon monoxide escapes in the "boil". The removal of dissolved or entrained oxides in the melt is carried out by the addition of deoxidants of silicon and manganese in the appropriate quantities to assure the required excess of these elements. Any additional alloy elements are added at this stage. The bath is then heated to tapping temperature.

The production of austenitic stainless steel by the arc furnace method is basically the same as for carbon steels. The high frequency induction furnace employs a direct melt process. The arc furnace method has a relatively new modification of direct application of oxygen into the melt in place of iron oxide, (Ref. 4.1).

4.11 The Arc Furnace Process. Normally austenitic stainless steel is produced in this method by a two slag process. The first charge consists of plain steel scrap and slag making material. The melt is produced rapidly, oxidizing additions made and the carbon restored to the desired low level. After the "boil" and removal of the first slag, a second slag is started by the addition of the alloy steel scrap. After melting, the bath composition is checked and alloy additions made to the desired composition, (Ref. 4.1). Chromium is usually added to the bath after the steel has been deoxidized. It is added as ferrochromium containing 68% chromium, 6% carbon and the balance iron.

4.12 The High Frequency Induction Process. This process is basically a melt process only. There is no significant oxidation, no oxidizing additions and no slag production. The charge is austenitic steel scrap which is rapidly melted, suitable alloy additions are made to adjust to the proper composition and the bath is tapped. This process uses 100% scrap for the charge, permits savings in melting time, close control of composition and quality may be maintained. The higher capital cost of the equipment prevents this method from more universal adoption, (Ref. 4.1).

4.13 Oxygen Lancing Modification. This method modifies the arc furnace process by the injection of oxygen directly into the molten bath. The method rapidly oxidizes the carbon without excessive oxidation of the chromium. It provides greater speed and control in the refining stage. The addition of oxygen in this way increases the temperature of the bath by 360F. At this higher temperature the stability of carbon monoxide is increased while the stability of the oxides of chromium, manganese, silicon and iron are decreased. The attack on the furnace refractories at the higher temperatures and the cost of the oxygen are the disadvantages to this modification in the arc furnace process, (Ref. 4.1).

4.14 Vacuum Melting. Induction and consumable electrode vacuum melts and remelts are available but all or almost all Type 301 produced is produced by air melt methods. Comparisions of air melted and vacuum melted Type 302 tensile and notched tensile properties at cryogenic temperatures were made. The results indicate higher tensile and yield strength but greater notch sensitivity for the vacuum melted heat as compared to the air melted heat. For 70 percent cold reduction, the martensite present for the vacuum melted heat was 91 percent as compared to 52 percent for the air melted heat. Based on data available from this study together with 140 similar tests performed on an other austenitic stainless steel leads to the possibility that the austenite is less stable for the vacuum melted than for the air melted material, (Ref. 4.3).

4.15 Casting Ingots. The bath of finished steel is cast into ingots for further processing to a particular form or product. Clean dry ladles are required and extremely clean ingot molds are necessary. Care must be taken to reduce to a minimum splashing in casting ingots. Splashing will increase oxidation and damage ingot surfaces. Badly damaged surfaces due to splashing will seriously increase manufacturing costs because of the necessity of heavy grinding required before deformation processes can be undertaken. Speed of casting is of great importance in order to minimize oxidation of the liquid steel. High chromium steels lose fluidity very rapidly if significant oxidation occurs, (Ref. 4.1).

4.2 Hot Working. The equipment that is used to heat and roll austenitic stainless steel ingots is the same as that used for carbon steel ingots. The austenitic stainless steels are generally stronger than ferritic steels at rolling temperatures and require more power for deformations.

The steel is susceptible to grain growth and overheating should be avoided. During the heating, special precautions should be taken to keep the sulfur content of the furnace or soaking pit atmospheres at a minimum because this steel after being heated in such atmospheres tends to tear and crack during rolling. The initial forging temperature range for Type 301 is 2100 to 2300F, (Ref. 4.2).

The ingots are rolled to blooms and slabs. The surfaces of bloom products are usually completely milled or planed to remove imperfections (conditioned). Slabs being difficult to roll may require an interruption in the process between ingot and slab for conditioning. The blooms used for the production of billet are also completely conditioned prior to heating for rolling, (Ref. 4.2).

Slabs are again conditioned prior to being rolled to plates. Ordinarily the slabs are conditioned completely. Occasionally the surface is satisfactory enough to condition only those areas surrounding defects. While the equipment for heating and rolling austenitic stainless steel plate is the same as for carbon steel plate, austenitic stainless steels require more power for rolling at elevated temperatures. Thus, the amount of reduction per pass is smaller for austenitic grades and the steel spreads less. After rolling, the plates are annealed and descaled by pickling, (Ref. 4.2).

Bars are rolled from conditioned billets.

Sheet and strip are usually rolled by the continuous method. Hot rolled coil is passed through a reversing mill to be cold rolled to sheet and strip and, depending on the finished thickness desired, an intermediate anneal and pickling may be used. A final anneal and pickling is performed, (Ref. 4.2).

4.3 Cold Working. Of the austenitic stainless steels, the Type 301 composition is best suited for the production of high strength steels by work hardening (see the discussion on cold working in Chapter 3).

CHAPTER 4 - REFERENCES

4.1 F. H. Keating, "Chromium-Nickel Austenitic Steels", Butterworths Scientific Publication, London, (1956)

4.2 J. M. Camp and C. B. Francis, "The Making, Shaping and Treating of Steel", 6th Edition, United States Steel Co., (1951)

4.3 J. Christian and A. Hurlich, "Mechanical Properties of Air Melted and Consutrode Melted Type 302 Stainless Steel at Room and Cryogenic Temperatures", General Dynamics/Astronautics, MRG-307, (April 4, 1962)

CHAPTER 5

MANUFACTURING PRACTICES

5.1 General. The various manufacturing processes of forming, cutting and machining vary from that in plain carbon steel due to the special properties of austenitic stainless steels. With proper equipment and tools the various manufacturing processes for Type 301 are not difficult to perform. Austenitic stainless steels in the annealed condition are tough rather than hard. They will tend to seize and gall in machining and require increased power in forming. The fundamental fact controlling the manufacturing processes of Type 301 is the unstability of the austenite phase and its tendency to break down to hard martensite under cold work. As the material is drawn , rolled, machined or cut, work hardening will take place making it increasingly more difficult to carry on the process. Often a slower rate of working is desirable and annealing between operations may be more frequently required than for other metals.

As can be seen in Table 5.1, approximately 40% cold rolling produces the full hard temper which is used for high strength-to-weight ratio applications. The extra-hard temper is produced by a 50 to 60 percent cold reduction. Of course, when heavily cold worked the formability is very limited. However, if the radii are reasonably generous the parts can be formed.

5.2 Forming. The alloy may be formed by drawing, spinning, rolling, wiper forming, stretch forming and press forming. Low yield strength and high ductility, which are characteristic of austenitic stainless steels in the annealed temper, permit successful forming of complex parts, (Ref. 5.10). As can be seen in Table 5.2, this alloy is very formable in the annealed condition. Type 301 lends itself well to deep drawing. Reductions in one draw of 40 percent, producing a 4 inch deep cup from a 10 inch blank, can be performed. Reduction as high as 50 percent is possible in one operation. Where multiple-step drawing is necessary each individual draw should not be more than 34 to 40 percent. Intermediate annealing may be necessary between drawing steps. In all severe reductions it is essential that strains be relieved immediately, by annealing, or the piece will crack within a few hours. Cracking may also occur following draws as a result of insufficient die clearance or improper lubrication, (Refs. 5.1, 5.2). Almost double the power used for equal drawing of ordinary carbon steels is required for this alloy. A speed of approximately one-half that used in regular draw work is appropriate. Clearance between punch and drawn die should be twice that used on carbon steels and a good lubricant must be applied uniformly over the surface to reduce friction, (Ref. 5.3).

For deep drawing, heavy-bodied lubricants and pigment-type lubricants must be used. For mild drawing, soluble oils or thinned pigment-type lubricants are satisfactory. The mill finish of the steel can greatly assist in retaining lubricants in deep drawing. Duller finishes assure better lubricant adhesion and thus minimize die wear and result in better finish of end products. Annealed and pickled finish is the appropriate mill finish for best results, (Ref. 5.1).

Proper die material is important in the successful drawing of stainless steel. Solid dies made from alloy tool steels of the non-deforming type (high carbon-high chromium) are most satisfactory for long wear. Cast iron dies may be used, but because of rapid wear are suitable only for short runs. Alloy cast iron, containing chromium and nickel, may also be used with good results, (Ref. 5.2).

While other austenitic stainless steels (such as Type 305) are preferred for spinforming, because of their slower rates of work hardening, Type 301 can be spun. In general, roller type tools are used and greater power and sturdier equipment is required for this operation, (Ref. 5.3). The lubricants recommended for drawing and spinning operations are:

1. Lithopane and boiled linseed oil in equal parts by volume and thinned with kerosene as necessary. To this powdered sulfur or talc may be added for difficult work.

2. White lead thinned with linseed oil to about the consistency of 600 W oil.

3. Castor oil and emulsified soap.

4. Lithopane mixed with water and applied in an even coat of moderate thickness. This should be allowed to dry before beginning operations, although it may be difficult to remove during cleaning operations.

5. Corn oil of the highest quality.

6. Powdered graphite mixed to a thin paste with water. This to be spread evenly over the work and allowed to dry before use. Thorough cleaning of the drawn parts is absolutely necessary before subsequent heating or annealing operations, (Ref. 5.2).

Roll or drawbench forming can be performed on Type 301 in the annealed condition up to full hard temper for bending and straight flange forming, (Ref. 5.4). Fig. 5.1 shows recommended minimum bend radii for 301 stainless for the various tempers. The smallest bend radius which can be formed without cracking is called the "minimum bend radius". The radius increases in proportion to the sheet thickness and temper. High carbon or alloy steel are satisfactory roll materials. Dilute solutions of water soluble oils make adequate lubricants. Soap solutions and extreme pressure oils give greater roll protection and produce a finer finish. However, they are more difficult to remove, (Ref. 5.1).

Wipe or compression forming is used for forming contours of changing radii in a single plane. Form blocks of steel and cast iron are generally used. Form block surfaces must be highly polished to prevent marking the surface, (Ref. 5.1).

Small springback and the absence of wrinkling in stretch forming make it an excellent method for forming Type 301. Form blocks may be made of wood, masonite, zinc, aluminum alloy or steel, depending on the quantity of parts to be produced. A heavy lubricant should be used at the ends of the die, light lubricants may be used in the center. Mechanical or hydraulic equipment are used to apply stretching tension. The ends must be tightly gripped to prevent slipping and it is recommended that grips with knurled surfaces be used, (Ref. 5.1).

Rocket motor cases have been stretched formed at cryogenic temperatures, yielding very high strength. Stretching to about 20 percent at -320F has produced strengths of 275 ksi in Type 301. Further strengthening of the material can be accomplished by age hardening at 800F for twenty hours producing strengths of 300 ksi, (Ref. 5.5).

Press or brake forming procedures that are used for carbon steel are applicable to Type 301. Because of the higher strength of Type 301 heavier tools are needed. A good rule for press forming procedure is to use the same forming procedure that would be used for hot rolled carbon steel four gages heavier than Type 301. The tool stroke should be as short as possible on bending a part to avoid fouling or scoring of the tool. Clearance between die and punch should be almost 10 percent more than metal thickness to reduce the tendency for ironing. Dies should be well polished and free from all surface blemishes. A lubricant similar to that used in drawing or rolling can be applied to reduce friction and metal adhesion to the die. For bending of annealed Type 301, a minimum radius of 1/2 the metal thickness is possible. Mechanical press forming may be used for form parts with contoured flanges with tempers up to and including 1/4 hard, (Ref. 5.1).

5.3 Cutting. The methods used for mechanical cutting of carbon steels can be used for Type 301. However, greater power and slower cutting speed must be employed. Such mechanical methods as shearing, blanking and punching, perforating, abrasive cutting and friction sawing are available for cutting stainless steel.

Flame cutting, as practiced on carbon steel, is not suitable for stainless steel. However, modifications in the method have been developed to make flame cutting of stainless steel possible.

Shearing of Type 301 requires 30-50 percent more power than is needed to shear carbon steel of the same gage. The shear knives should be made of high speed steel or suitable tool steel and ground with a lip rake of about 2°. The blades should be sharp and maintain a very close adjustment to prevent dragging of the metal. Type 301 does not snap or break during shearing operation as do most metals. They must be cut all the way through. Clearances should be 1/20 of the metal thickness with a maximum of 0.003 inches. It is better to make a long continuous cut rather than to chop off the metal. Hand snipping requires the same precautions as shearing. Blades must be kept sharp and closely adjusted to prevent dragging of the metal, (Ref. 5.1).

The best grade of tool steel should be used for blanking and punching dies. They should be kept sharp, rigidly backed and clearance should be close. Suggested clearances are as for shearing, 1/20 of the metal thickness with a maximum of 0.003 inches. The power for blanking or punching must be 50 percent higher and speed 2/3 of that for carbon steels, (Ref. 5.1).

Perforating stainless steel can be done with little difficulty. Twice the power and half the speed that would be used for carbon steel is required. Top grade tool steels with sharp cutting edges and close clearances are necessary. The same clearances are required as for punching and blanking. Hole diameters twice the thickness of the material or more are recommended. For best results, a thin drawing or cutting lubricant should be used for punching minimum diameter holes, (Ref. 5.1). Abrasive wheel cutting speeds of 1/4 square inch per second for dry cutting and 1/8 square inch per second for wet cutting are obtainable. The recommended wheel speeds are 10,000 sfm for 12 inch diameter wheels and 16,000 sfm for 10 inch diameter wheels. Cutting with rubber-banded wheels are recommended to reduce heat-tinting or burning, (Ref. 5.1).

Recommendations for friction sawing are given in Table 5.3. The best feeds and speeds for an actual job should be determined by trial and error using the Table values on the first trial. The finish produced by friction sawing should be smooth and even with a 1/32 inch to 1/16 inch burr on the underside of the cut. The saw width is from 3/16 inch to 1 inch depending upon the contour of the cut. In general, saws should be as wide as possible for the radius of the cut. Saw set ranges from 0.042 inch to 0.057 inch depending on the saw width, (Ref. 5.1).

Flame cutting procedures used for carbon steels will produce refractory oxides so resistant to the heat of the torch that they will not burn away quickly. In this way flame cutting becomes a melting process which is too inaccurate to be practiced. Two methods have been developed as a modification of the usual oxy-acetalene equipment that makes flame cutting of stainless steel possible. In the powder cutting method, metallic iron is introduced into the cutting zone. This would oxidize rapidly liberating a great deal of local heat which is high enough to melt the refractory oxides rapidly. The oxides are then floated away as slag. In flux injection cutting, a flux is introduced to the cutting zone which combines with the refractory oxides chemically to produce a lower melting compound that is easily flushed away, (Ref. 5.1).

5.4 Machining. Because of the work hardening characteristics of Type 301, certain precautions and modifications of machining methods used for mild carbon steels must be employed. However, Type 301 will machine with little trouble as long as the proper tools and lubricants are selected. Rigidity is a necessary factor to prevent chatter and springing and consequently hard spots in the metal. Oversize motors are recommended for all equipment since they also will permit heavy cuts without chattering. Precautions should be taken to prevent the tool from riding on or glazing the work. Tools should be kept sharp to prevent the surface from hardening due to rubbing action. Proper selection of the cutting tool may also be the deciding factor for successful machining. Table 5.4 shows recommended cutting speeds and feed speeds for various tool materials and machining operations. The procedures listed here can only act as a guide. Most production men who machine stainless steel will start with the average speeds recommended and feel their way to the proper cutting speeds and feed speeds for their own particular tools, equipment and applications, (Refs. 5.1, 5.6).

In drilling Type 301, as short a drill as the job permits should be used. This will reduce whipping. When marking for drilling, a prick punch should not be used since this will work harden the metal and make starting of the drill difficult. A square or triangular punch should be used. The drill should not be allowed to ride in the hole. This will glaze the bottom, forming a hardened surface and make continued drilling more difficult. Drills should be kept sharp to reduce glazing. Back-up plates of an easily machined metal should be used to reduce burring. To prevent chip packing, the drill should be backed out periodically. The depth of the first drill may be the drill diameter, then back out. Drill in successive bites, two diameters and one diameter. Where drill size permits, a chip breaker should be ground parallel to the cutting edge. Water soluble oils are generally satisfactory for cooling the drill. Sometimes it may be necessary to use sulfurized, chlorinated, mineral or fatty oils. Tap clearance should be 6° to 8°, point angle 135° to 140°. A high hook angle with two flute, gun-type taps are preferred. Hole tapping is relatively easy, particularly if the thread length is short. Hook angles from 15° to 20° are recommended.

Spiral pointed taps will work well in open holes up to 3/8 inch. Spiral fluted taps, with flutes having the opposite hand as the threads, is preferred in larger holes. Blind holes are more difficult. Room must be allowed for chips in deep holes. These chips are difficult to break when the tap reverses. Chamfer should be as long as possible and the chamfer angle should be greater than 9° with the tap axis.

Flutes with a spiral of the same hand will help in chip removal. The special angle should not be too large or tearing and oversize threads will result. Filling blind holes with heavy paste or grease helps in chip removal. Holes to be tapped must be properly sized. The taps should be as large as possible, especially when a fine pitched thread is used. Correct lubrication must be provided for successful tapping. A mixture of sulfur-chlorinated petroleum oils with active sulfur are generally suggested. The lubricants should be placed in the hole rather than on the tap and should be continuous if possible, (Ref. 5.1).

Self-opening dies are recommended for threading. Solid dies will cut satisfactory threads, but are more likely to tear them when they are backed-off. The standard thread chasers are used with a slightly modified grind. Die heat chasers for straight threads should be ground with almost a 15° hook angle. Tangent and circular type chasers require a rake angle of 20° to 25°. External pipe thread chasers should have a 10° hook angle. Tap chasers should have a 20° lip hook for straight threads and a 15° radial hole for tapered threads. A mixture of sulfur base and paraffin base oils is recommended as a proper lubricant for successful threading, (Ref. 5.1).

Sharp tools are very important in the turning operation. They should be as large as possible in order to dissipate heat away from the cutting area. Front and side clearance angles should be no more than 10°. Top rake should be 5° to 10° with slight nose radius. Chip breakers or curlers should be used where possible. Chip curlers are particularly important for making heavy cuts. The flat blade or circular parting tools may be used. They should provide 7° to 10° top rake and at least 3° side clearance. If parting is deep, a degree or two additional clearance may be necessary, (Ref. 5.1).

Milling cutters should have a positive rake as great as, or greater than, that used for carbon steels. This should be from 10° to 20° positive. The axial rake angle should be high to provide for smooth cutting. Saws and slotting cutters require a rake from 0° to 15°, and end and plain mills should have axial rake to 15° to 50° positive. The relief angle may vary from 5° to 10°; the larger the cutter, the smaller the angle. A lubricant must be used in milling, (Ref. 5.1).

Type 301 can be broached. The broach must be without nicks on the cutting edge. The back-off angle on internal broaches should range from 2° to 5°. Larger angles will shorten the life of the broach. The recommended lubricant for broaching is a sulfur-base paraffin-base oil mixture, (Ref. 5.1).

In reaming, enough metal should be allowed such that the tool can take a definite cut. A high speed spiral fluted reamer with a 30° to 35° chamfer angle and a 7° helix is suggested. Taper reaming may be performed on Type 301 and an ordinary finish can be obtained in this way. For precision work, a taper reaming attachment should be used. All reaming must be well lubricated with sulfurized oil, (Ref. 5.1).

TYPICAL MECHANICAL PROPERTIES OF WROUGHT 301 AUSTENITIC STAINLESS STEEL PLATE, SHEET AND STRIP AT ROOM TEMPERATURE

TABLE 5.1

Source	(Ref. 5.9)			
Form and Condition	F_{tu}-ksi	F_{ty}-ksi	e(2 in)	Hardness
Sheet and strip				
Annealed	110	40	60	85 (a)
1/4 Hard	125*	75*	25*	25 (b)
1/2 Hard	150*	110*	15*	32 (b)
3/4 Hard	175*	135*	10*	37 (b)
Full Hard	185*	140*	8*	41 (b)
Extra Hard	225*	215*	1	43 (b)
20% Cold Rolled	155	109	27	32 (b)
40% Cold Rolled	187	141	15	37 (b)
Plate				
Annealed	105	40	55	165 (c)

(a) Rockwell B Hardness
(b) Rockwell C Hardness
(c) Brinell Hardness
* Minimum value

RELATIVE FORMABILITY OF ANNEALED AUSTENITIC STAINLESS STEEL IN ORDER OF DECREASING FORMABILITY *

TABLE 5.2

Source	(Ref. 5.11)				
	Type of Forming Operation				
180° Bend 0.010 inch Min Radius or 10% Stretch	Stretch 10 to 20%	20 to 30%	30 to 35% (a)	30 to 35%(b)	>35% (a)
301	301	301	301	301	301
201	201	201	201	201	201
302	302	302	302	302	-
202	202	202	202	202	-
305	305	305	305	-	-
304	304	304	-	-	-
316	316	316	-	-	-
321	321	321	-	-	-
347	347	347	-	-	-
309	309	-	-	-	-
310	-	-	-	-	-

(a) Possible buckling
(b) No buckling
* Grades are listed in the order of decreasing ability to form parts having the indicated severity without intermediate annealing.

(Ref. 5.11)

FRICTION SAWING

TABLE 5.3

Source	(Ref. 5.1)		
Metal thickness inches	Saw pitch - feet per inch	Saw speed - feet per minute	Cutting rate - feet per minute
1/16	18	3,000- 6,000	120
1/8	14	3,000- 6,000	75
1/4	10	6,000- 9,000	55
1/2	10	9,000-12,000	20
3/4	10	12,000-15,000	10
1	10	12,000-15,000	6

MACHINING RECOMMENDATION FOR TYPE 301 STAINLESS STEEL

TABLE 5.4

Source	(Ref. 5.12)							
Operation	Condition Hardness - BHN	Cutting Conditions	High Speed Tool Speed fpm	High Speed Tool Feed ipr	High Speed Tool Tool mat'l	Carbide Tool Speed fpm	Carbide Tool Feed ipr	Carbide Tool Tool mat'l
Turning Single point and Box Tools	Annealed 135-185	0.150 in, depth of cut	80	0.015	T5, T15	275	0.015	C-2
		0.025 in, depth of cut	100	0.007	T5, T15	335	0.007	C-3
	Cold Drawn 225-275	0.150 in, depth of cut	75	0.015	T5, T15	250	0.015	C-2
		0.025 in, depth of cut	95	0.007	T5, T15	300	0.007	C-3
Turning Form Tool	Annealed 135-185	0.500 in, form tool width	60	0.003	T5, T15	205	0.005	C-2
		0.750 in, form tool width	60	0.0025	T5, T15	205	0.004	C-2
		1.000 in, form tool width	60	0.0025	T5, T15	205	0.004	C-2
		1.500 in, form tool width	60	0.002	T5, T15	205	0.0035	C-2
		2.000 in, form tool width	60	0.002	T5, T15	205	0.0035	C-2
	Cold Drawn 225-275	0.500 in, form tool width	55	0.003	T5, T15	190	0.005	C-2
		0.750 in, form tool width	55	0.0025	T5, T15	190	0.004	C-2
		1.000 in, form tool width	55	0.0025	T5, T15	190	0.004	C-2
		1.500 in, form tool width	55	0.002	T5, T15	190	0.0035	C-2
		2.000 in, form tool width	55	0.002	T5, T15	190	0.0035	C-2
Boring	Annealed 135-185	0.010 in, depth of cut	80	0.004	T5, T15	275	0.005	C-3
		0.050 in, depth of cut	75	0.005	T5, T15	260	0.007	C-3
		0.100 in, depth of cut	70	0.007	T5, T15	250	0.009	C-3
	Cold Drawn 225-275	0.010 in, depth of cut	75	0.004	T5, T15	250	0.005	C-3
		0.050 in, depth of cut	70	0.005	T5, T15	240	0.007	C-3
		0.100 in, depth of cut	65	0.007	T5, T15	225	0.009	C-3

TABLE 5.4 (continued)

Source	(Ref. 5.12)							
Operation	Condition Hardness - BHN	Cutting Conditions	High Speed Tool Speed fpm	High Speed Tool Feed ipr	High Speed Tool Tool mat'l	Carbide Tool Speed fpm	Carbide Tool Feed ipr	Carbide Tool Tool mat'l
Face Milling	Annealed 135-185	0.150 in, depth of cut	95	0.006	M-2	325	0.010	C-2
		0.025 in, depth of cut	125	0.005	M-2	400	0.008	C-3
	Cold Drawn 225-275	0.150 in, depth of cut	85	0.006	M-2	275	0.010	C-2
		0.025 in, depth of cut	100	0.005	M-2	350	0.008	C-3
End Milling Profiling	Annealed 135-185 (0.050 in, depth cut)	1/4 in cutter diameter	90	0.001	M-2, M-6	225	0.001	C-2
		1/2 in cutter diameter	90	0.002	M-2, M-6	225	0.002	C-2
		3/4 in cutter diameter	90	0.002	M-2, M-6	225	0.003	C-2
		1 to 2 in cutter diameter	90	0.003	M-2, M-6	225	0.005	C-2
	Cold Drawn 225-275 (0.050 in, depth cut)	1/4 in cutter diameter	70	0.001	M-2,M-10	175	0.001	C-2
		1/2 in cutter diameter	70	0.002	M-2,M-10	175	0.002	C-2
		3/4 in cutter diameter	70	0.002	M-2,M-10	175	0.003	C-2
		1 to 2 in cutter diameter	70	0.003	M-2,M-10	175	0.004	C-2
Drilling	Annealed 135-155	1/8 in nominal hole diam		0.003	(a)			
		1/4 in nominal hole diam	50	0.003				
		1/2 in nominal hole diam		0.005				
		1 in nominal hole diam		0.010				
		2 in nominal hole diam		0.016				
	Cold Drawn 225-275	1/8 in nominal hole diam	45	0.002	(a)			
		1/4 in nominal hole diam		0.003				
		1/2 in nominal hole diam		0.005				
		1 in nominal hole diam		0.011				
		2 in nominal hole diam		0.016				

(a) M-10, M-1, M-7

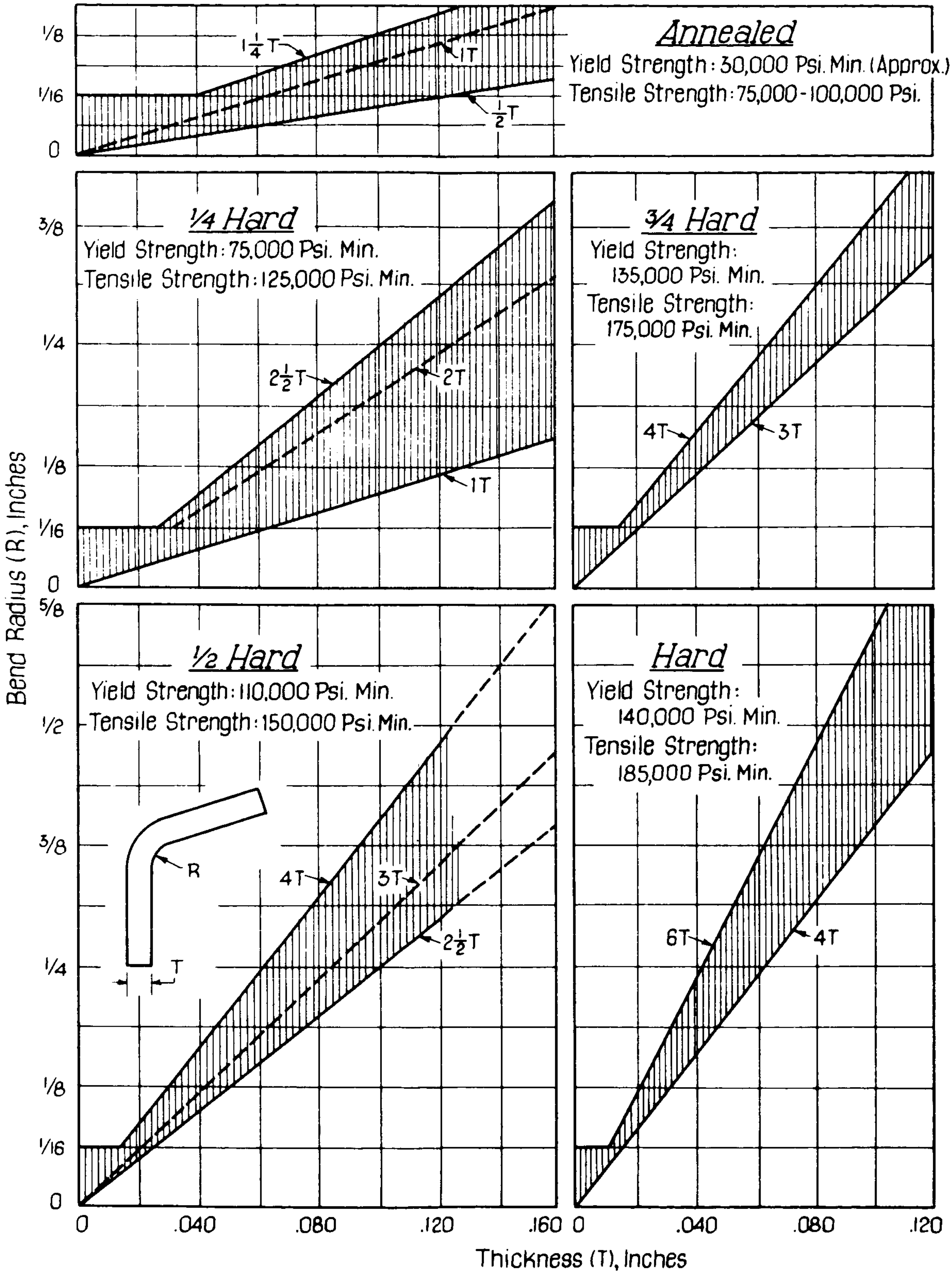

FIG. 5.1 RECOMMENDED MINIMUM BEND RADII FOR TYPE 301 STAINLESS FOR VARIOUS TEMPERS

(Ref. 5.10)

CHAPTER 5 - REFERENCES

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5.2 "Fabrication, U. S. Stainless and Heat Resisting Steels", United States Steel Co., (1946)

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5.5 "High Performance Pressure Vessels Produced by Cryogenic Sheet Forming", Arde-Portland Inc., Report D-30715E, (May 15, 1964)

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5.9 "Wrought Austenitic Stainless Steels", Materials in Design Engineering, Materials and Process Manual, No. 224, (October 1964), p. 115-126

5.10 "Forming of Austentic Chromium-Nickel Stainless Steels", International Nickel Company, Inc., 2nd Edition, (1954)

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CHAPTER 6

SPACE ENVIRONMENT EFFECTS

6.1 General. The austenitic stainless steels are used successfully in both structural and non-structural applications for launch vehicles and spacecraft. In general, these alloys are relatively insensitive to degradation under typical space environment conditions. The vapor pressures of stainless steels are sufficiently high, (Fig. 6.1), so that the combined temperature-vacuum effects are negligible. Nuclear and space indigenous radiation induced defects do not appear to significantly affect mechanical and physical properties, at room ambient and elevated temperatures, below accumulated doses of about 1×10^{19} neutrons/cm^2 or greater, (Ref. 6.2). At these high doses, slight embrittlement takes place, resulting in increases in hardness and in some physical properties and a decrease in creep rate. Fatigue properties do not appear to be affected significantly. When irradiated at cryogenic temperatures, the dose threshold may be lowered by one or two decades, but the probabilities of encountering doses on this order of magnitude are extremely remote except in the vicinity of nuclear reactors.

Elevated temperatures, hard vacuums, high energy radiations, and micrometeoroids can individually and collectively influence the surface characteristics of stainless steels by desorption processes and erosion. These phenomena are of importance if optical properties, lubrication, certain electrical properties, etc. are critical design parameters. Sputtering of the surface by atomic or molecular particles can deteriorate surface finishes in a relatively short period. The sputtering process is associated with a minimum threshold energy value for atomic or molecular particles striking a material surface. Typical values which have been obtained for this threshold energy are 6, 11 and 12 ev for O, N_2 and O_2 particles, respectively, to remove one or more atoms from the materials surface upon which they impinge, (Ref. 6.3). Loss of metal by this mechanism can vary over a wide range and the greatest loss may be expected during solar storms, (Ref. 6.4). However, loss of metal by sputtering has little structural significance, although it may seriously affect optical and emissive properties of the material surface. Estimates of surface erosion by sputtering are presented in Table 6.1.

Micrometeoroids can produce surface erosion similar to sputtering but on a more macroscopic scale, and may aso produce punctures. They vary widely in mass, composition, velocity and flux; generalizations about rates of erosion and penetration, therefore, must be used with care. The predicted frequency of impact as a function of meteoroid mass is given in Fig. 6.2. Data are given in Fig. 6.3 on the hit rate versus crater depth for steel and aluminum.

The surface erosion of stainless steels due to corpuscular radiation is probably insignificant, amounting to something in the order of 10 μ per year. Indigenous space radiation, however, will tend to accelerate the removal of surface films on stainless steels. The removal of such films might result in loss of lubricity and an increased propersity to "cold welds". The interaction of indigenous radiation with desorption gases might cause some spurious, transient electrical conditions if the alloy is used for electrical applications.

TABLE 6.1

Source	Ref. 6.2
Data	Surface Removal by Sputtering in Space
Nitrogen and oxygen	100 Å/year
Radiation belt protons and heavy ions	0.2 Å/year
Solar flare protons	100 Å/year
Solar proton emission	3 Å/ year
Cosmic rays	Insignificant
Meteoroids	< 30 Å/year

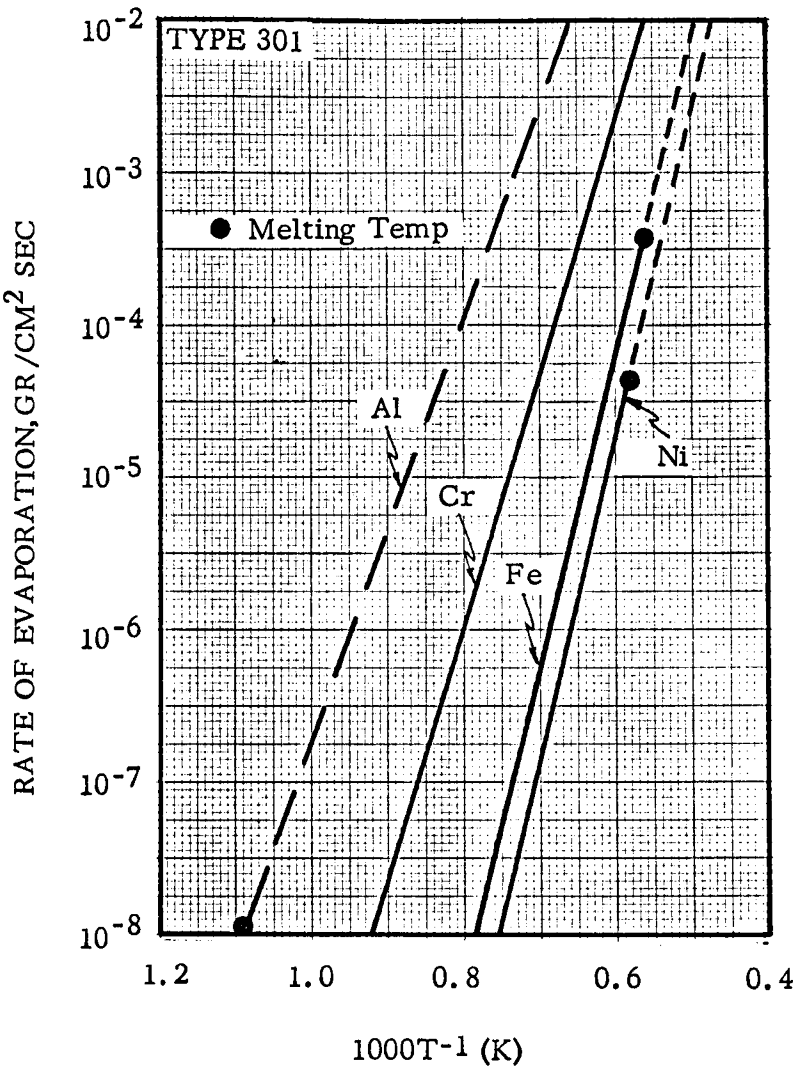

FIG. 6.1 EVAPORATION RATES FOR MAJOR ELEMENTS IN AUSTENITIC STAINLESS STEELS COMPARED TO ALUMINUM

(Ref. 6.1)

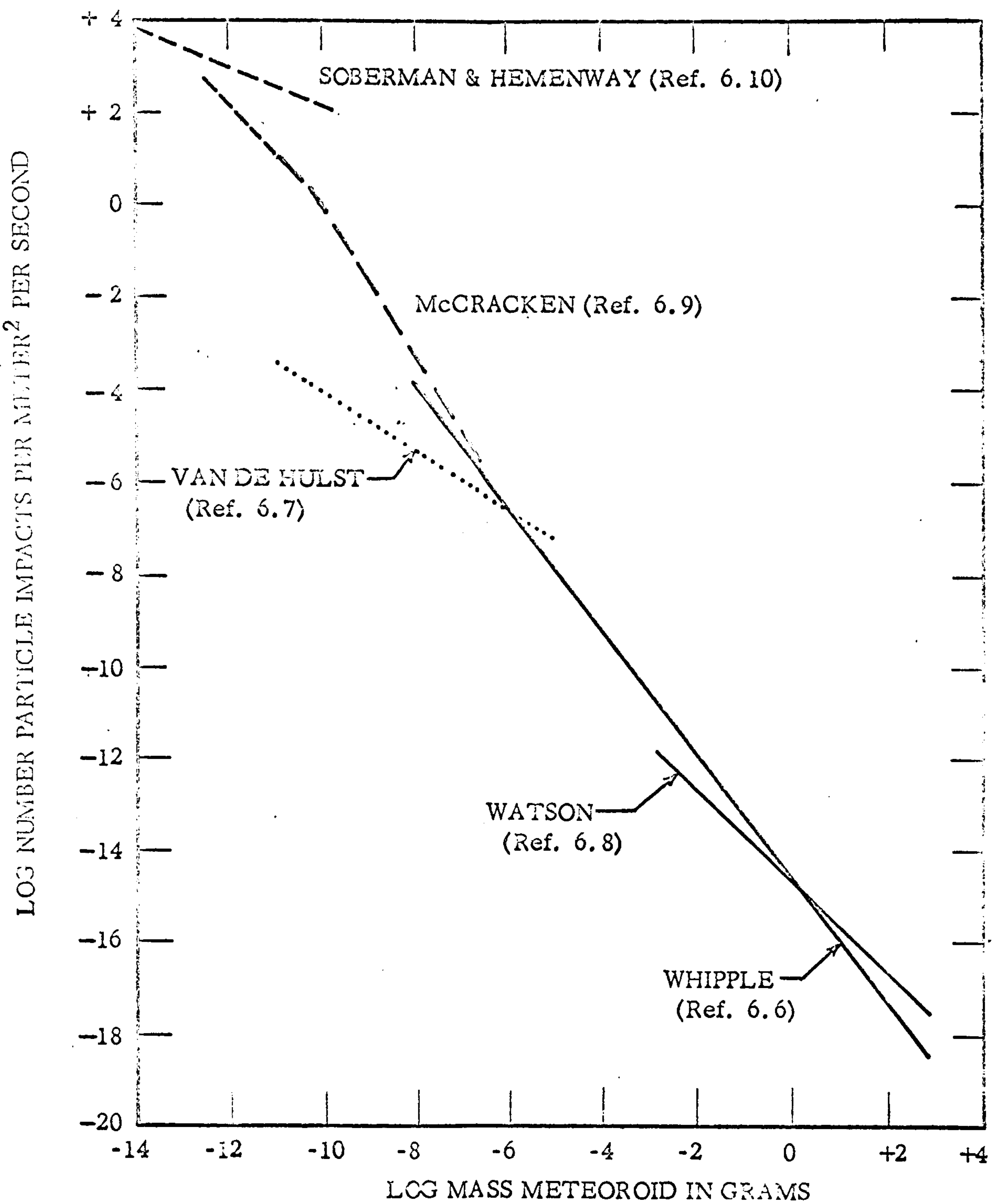

FIG. 6.2 CUMULATIVE METEOROID IMPACT RATES NEAR THE EARTH (Ref. 6.2)

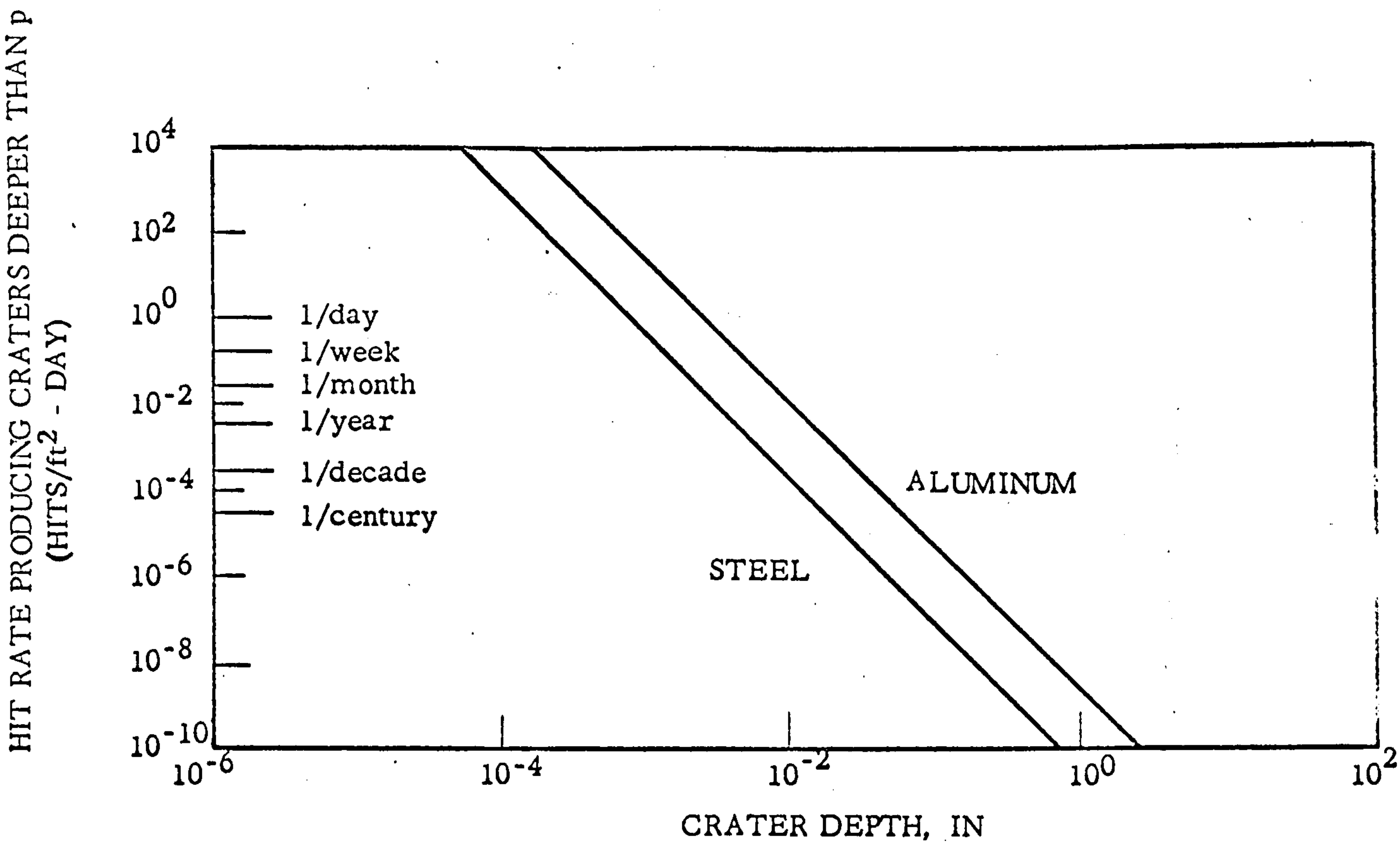

FIG. 6.3 HIT RATE vs CRATER DEPTH IN THE EARTH NEIGHBORHOOD BUT WITHOUT EARTH SHIELDING

(Ref. 6.5)

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CHAPTER 7

STATIC MECHANICAL PROPERTIES

7.1 Specified Properties
7.11 NASA (none known)
7.12 AMS specified properties
7.121 AMS specified mechanical properties for sheet and strip, Table 7.121.
7.13 Military specified properties
7.14 Federal specified properties
7.15 ASTM specified properties
7.151 ASTM specified properties for plate, sheet and strip, Table 7.151.

7.2 Elastic Properties and Moduli
7.21 Poisson's ratio
7.22 Young's modulus of elasticity, E.
7.221 Design values of E, E_c and G, Table 7.221.
7.222 Typical value of E. 28.0 x 10^3 ksi, (Refs. 7.5 and 7.6).
7.223 Modulus of elasticity of sheet and rod at low temperatures, Fig. 7.223.
7.224 Modulus of elasticity for 1/2 hard sheet at room and elevated temperatures, Fig. 7.224.
7.23 Compression modulus, E_c.
7.231 Design value of E_c, see Table 7.221.
7.24 Modulus of rigidity (shear modulus), G.
7.241 Design value of G, see Table 7.221.
7.25 Tangent modulus
7.251 Typical tangent modulus curves in tension for sheet and plate, Fig. 7.251.
7.252 Tangent modulus curves in compression for sheet in various conditions, Fig. 7.252.
7.26 Secant modulus

7.3 Hardness
7.31 Effect of aging temperature on hardness of 67 percent cold rolled sheet, Fig. 7.31.
7.32 Effect of hydrogen environment at elevated temperatures on surface hardness of 1/2 hard sheet, Fig. 7.32.
7.33 AISI typical hardness values, Table 7.33.

7.4 Strength Properties
7.41 Tension
7.411 Design tensile properties
7.4111 Design properties for plate, sheet and strip, Table 7.4111.

7.45 Bearing

7.451 Design bearing properties, see Table 7.4111.

7.452 Effect of test temperature and exposure time on bearing properties of 60 percent cold reduced sheet, Fig. 7.452.

7.46 Fracture

7.461 Notch strength

7.4611 Effect of test temperature and exposure time on notch strength of 60 percent cold reduced sheet, Fig. 7.4611.

7.4612 Effect of cold reduction and test direction on sharp notch strength of sheet, Fig. 7.4612.

7.4613 Effect of test temperature on net fracture sheet of full hard sheet, Fig. 7.4613.

AMS SPECIFIED MECHANICAL PROPERTIES FOR SHEET AND STRIP

TABLE 7.121

Source	Ref. 7.1	Ref. 7.2		Ref. 7.3	
Alloy	Type 301				
Form	Sheet and Strip (a)				
Condition	1/4 Hard	1/2 Hard		Full Hard	
Thickness, in	None Given	$\leq$ 0.015	> 0.015	$\leq$ 0.015	> 0.015
F_{tu}, ksi -min	125	150	150	185	185
-max	150	-	-	-	-
F_{ty}, ksi -min	75	110	110	140	140
-max	-	-	-	-	-
e(2in), -min, percent	40	15	18	8	9

(a) For widths 9 inches and over, tensile specimens shall be taken with the axis perpendicular to the direction of rolling.
For widths less than 9 inches, tensile specimens shall be taken with the axis parallel to rolling direction.

ASTM SPECIFIED PROPERTIES FOR PLATE, SHEET AND STRIP

TABLE 7.151

Source	Ref. 7.4				
Alloy	Type 301				
Form	(a)	Sheet and Strip			
Specification	A167-63	A177-58			
Condition	Ann	1/4 Hard	1/2 Hard	3/4Hard	Full Hard
F_{tu}, min-ksi	75.0	125.0	150.0	175.0	185.0
F_{ty}, min-ksi	30.0	75.0	110.0	135.0	140.0
e(2 in), min-percent					
$\leq$ 0.015 in	40	25	9	3	3
0.016-0.030 in	40	25	10	5	4
$\geq$ 0.031 in	40	25	10	7	5
Hardness, max					
Brinell	202	-	-	-	-
RB	88	-	-	-	-

(a) Plate, sheet and strip

DESIGN VALUES OF E, E_c AND G

TABLE 7.221

Source	Ref. 7.9				
Alloy	Type 301				
Form	Plate, Sheet and Strip (a)				
Basis	S (Specification)				
Condition	Ann	1/4 Hard	1/2 Hard	3/4 Hard	Full Hard
E, 10^3 ksi L	29.0	27.0	26.0	26.0	26.0
T	29.0	28.0	28.0	28.0	28.0
E_c, 10^3ksi L	28.0	26.0	26.0	26.0	26.0
T	28.0	27.0	27.0	27.0	27.0
G, 10^3 ksi	12.5	12.0	11.5	11.0	11.0

(a) Only annealed condition applicable to plate.

AISI TYPICAL HARDNESS VALUES

TABLE 7.33

Source	Ref. 7.14	
Alloy	Type 301	
Property	Hardness	
Form	Condition	Hardness value (aver)
Sheet, strip	Ann	85 RB
	1/4 hard	25 RC
	1/2 hard	32 RC
	3/4 hard	37 RC
	Full hard	41 RC
Plate	Ann	165 BHN

DESIGN PROPERTIES FOR PLATE, SHEET AND STRIP

TABLE 7.4111

Alloy	AISI 301 [a]				
Form	Plate [b], sheet, and strip				
Condition	Annealed	¼ hard	½ hard	¾ hard	Full hard
Basis	S	S	S	S	S
Mechanical properties:					
F_{tu}, ksi:					
L	75	125	150	175	185
T	75	125	150	175	185
F_{ty}, ksi:					
L	30	75	110	135	140
T	30	75	110	135	140
F_{cy}, ksi:					
L	35	43	58	76	85
T	35	80	118	160	179
F_{su}, ksi	40	67.5	80	95	100
F_{bru}, ksi:					
(e/D=1.5)	...	...	...	...	...
(e/D=2.0)	150	250	300	350	370
F_{bry}, ksi:					
(e/D=1.5)	...	...	...	...	...
(e/D=2.0)	50	140	200	240	270
e, percent	([c])	([c])	([c])	([c])	([c])

S - Property value indicated is the specified minimum value of the governing Military or AMS specification for this material.

(a) Properties for annealed condition also applicable to annealed 302, 303, 304, 321 and 327 stainless steels

(b) Only annealed condition is applicable to plate

(c) See elongation table below:

Condition	Thickness, inches	Elongation, percent
Annealed	0.015 and under	40
	0.016 to 0.030	45
	0.031 and over	50
Quarter-hard	0.015 and under	25
	0.016 and over	25
Half-hard	0.015 and under	15
	0.016 and over	18
Three quarter-hard	0.015 and under	10
	0.016 and over	12
Full-hard	0.015 and under	8
	0.016 and over	9

AISI GUARANTEED TENSILE PROPERTIES

TABLE 7.4112

Source	Ref. 7.14				
Alloy	Type 301				
Form	Sheet and Strip				
Condition	Cold Rolled				
	Ann	1/4H	1/2H	3/4H	Full H
F_{tu}, min-ksi	110(a)	125	150	175	185
F_{ty}, min-ksi	40(a)	75	110	135	140
e, min-percent					
$\leq$ 0.015 in	50	25	15	10	8
0.016-0.024 in	50	25	18	12	9
> 0.025 in	55	25	18	12	9

(a) Maximum value

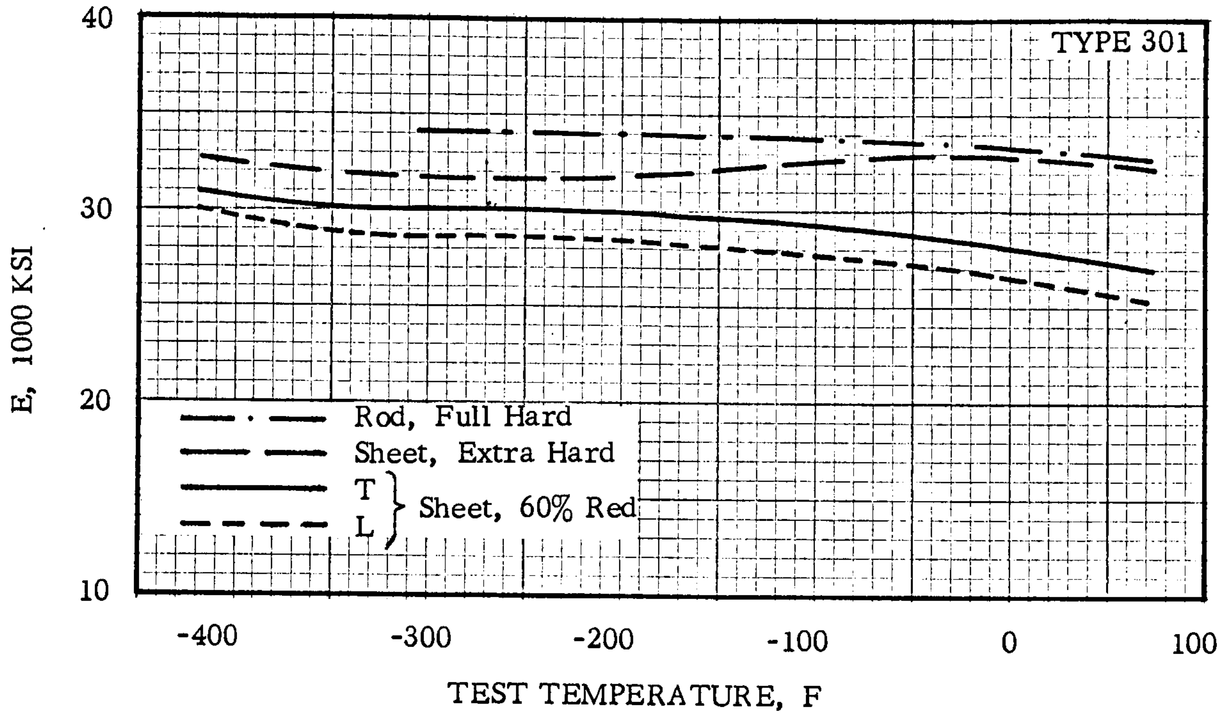

FIG. 7.223 MODULUS OF ELASTICITY OF SHEET AND ROD AT LOW TEMPERATURES (Ref. 7.8)

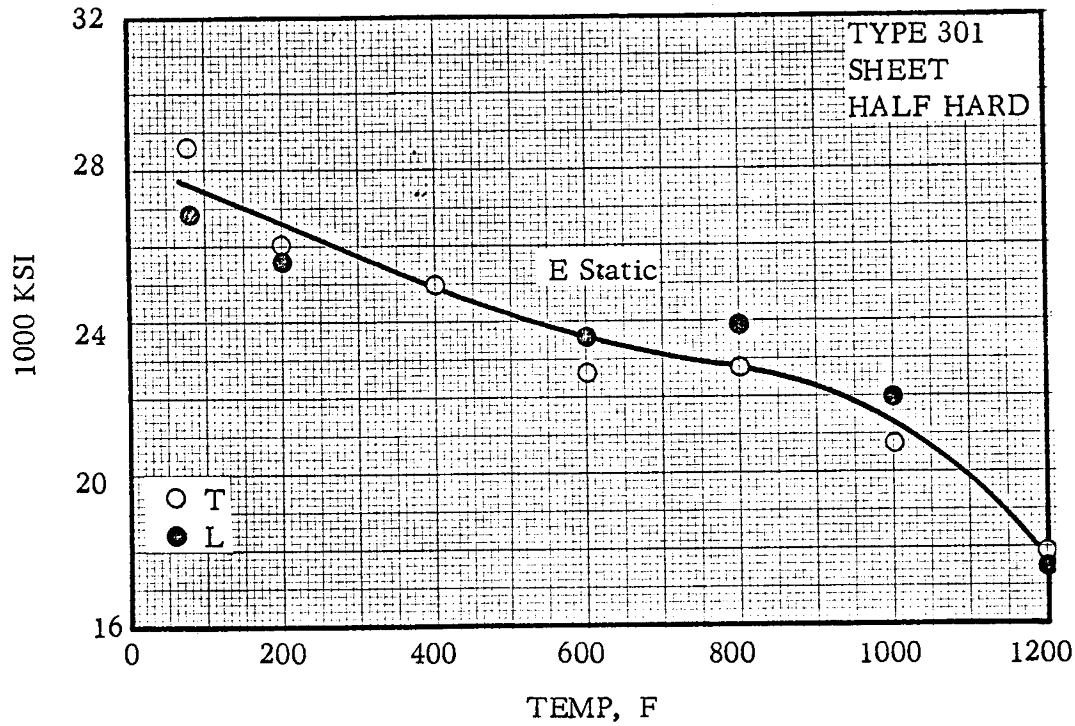

FIG. 7.224 MODULUS OF ELASTICITY FOR TYPE 301 1/2 HARD SHEET AT ROOM AND ELEVATED TEMPERATURES

(Ref. 7.7)

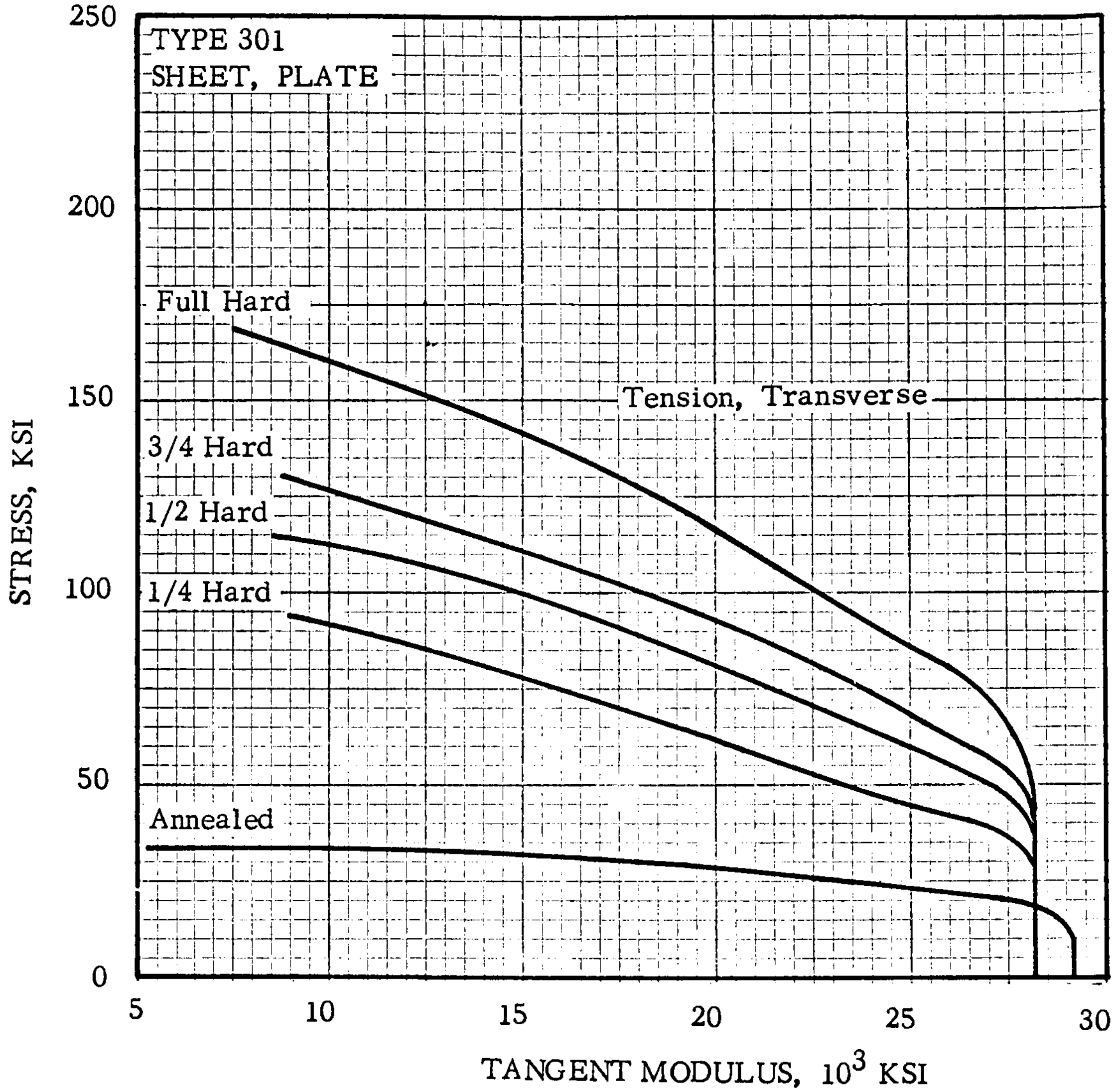

FIG. 7.251 TYPICAL TANGENT MODULUS CURVES IN TENSION FOR SHEET AND PLATE

(Ref. 7.9)

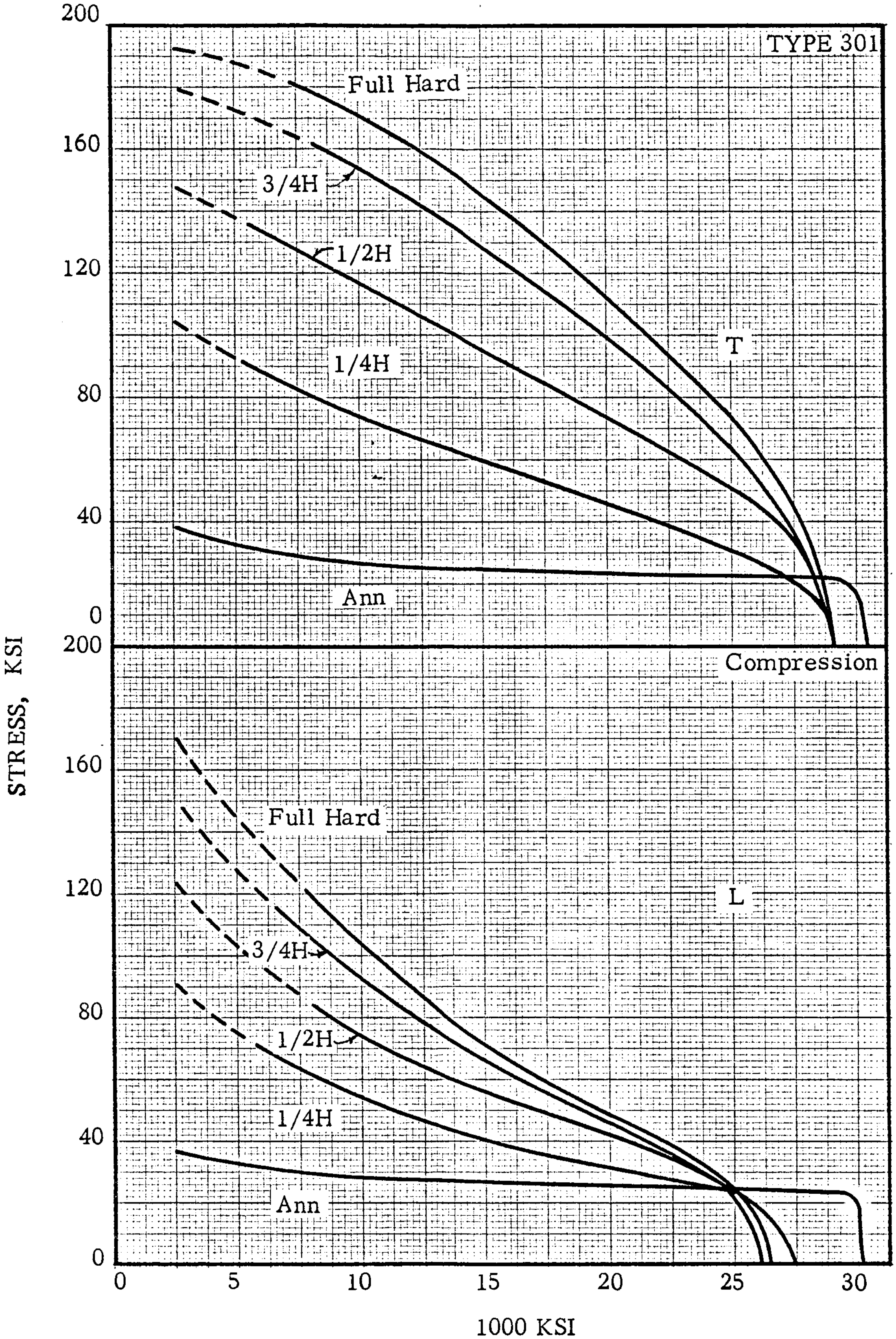

FIG. 7.252 TANGENT MODULUS CURVES IN COMPRESSION FOR TYPE 301 SHEET IN VARIOUS CONDITIONS

(Ref. 7.10)

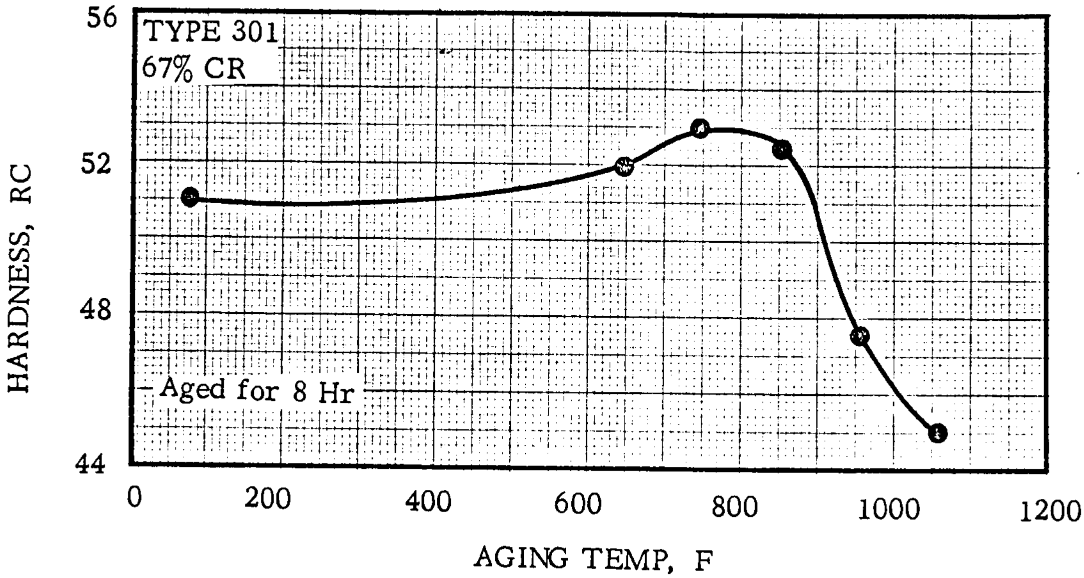

FIG. 7.31 EFFECT OF AGING TEMPERATURE ON HARDNESS OF 67 PERCENT COLD ROLLED SHEET

(Ref. 7.11)

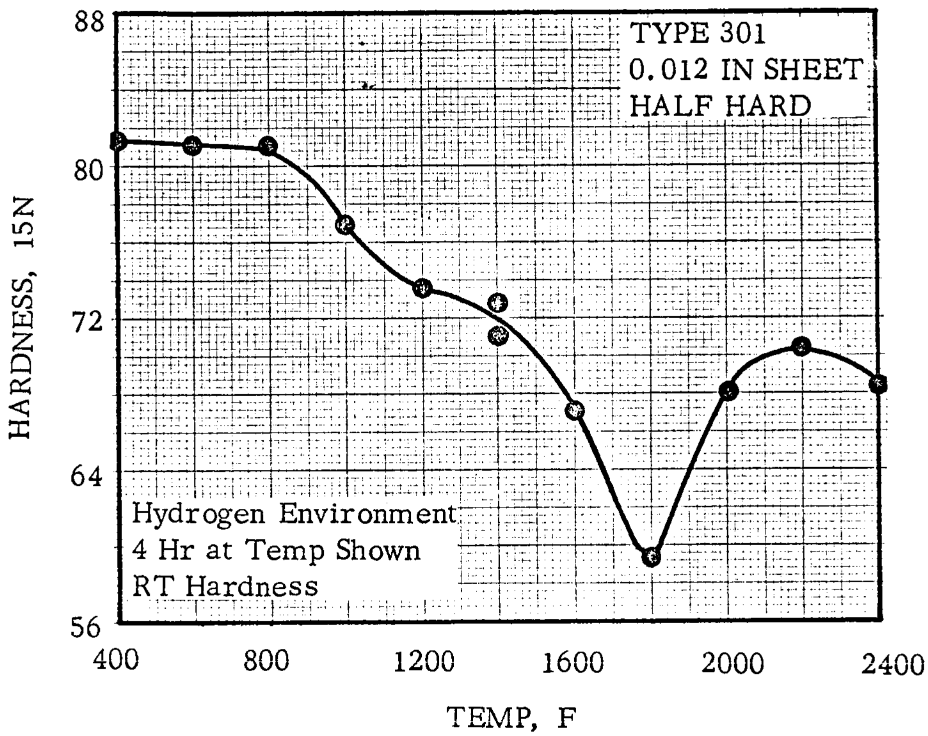

FIG. 7.32 EFFECT OF HYDROGEN ENVIRONMENT AT ELEVATED TEMPERATURE ON SURFACE HARDNESS OF HALF HARD SHEET

(Ref. 7.12)

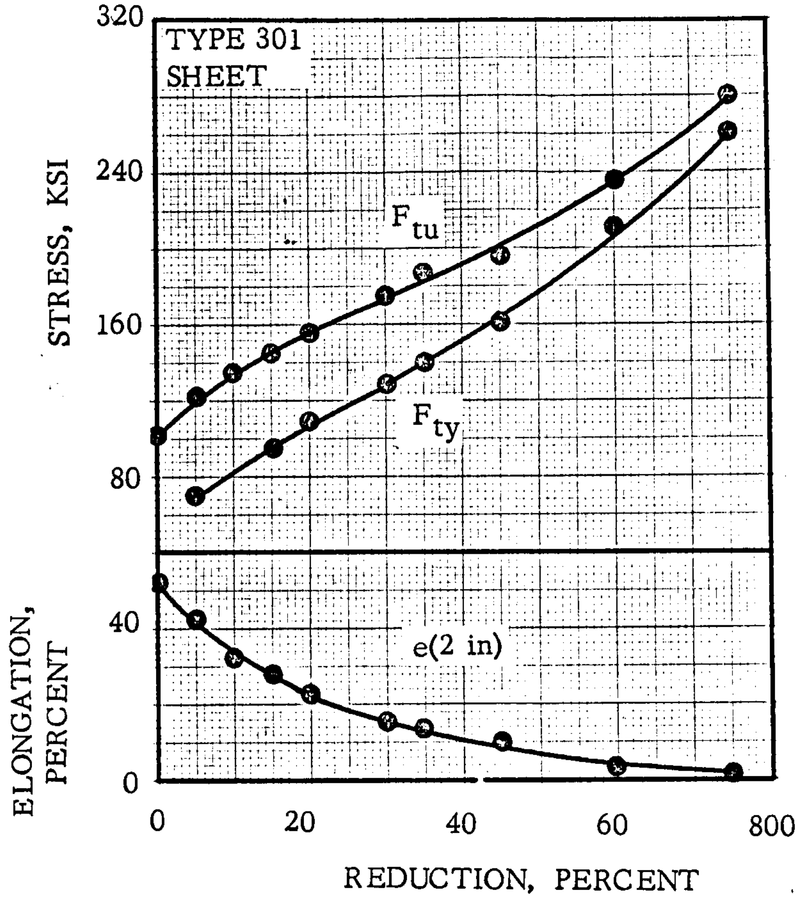

FIG. 7.4113 EFFECT OF COLD REDUCTION ON TENSILE PROPERTIES OF SHEET

(Ref. 7.13)

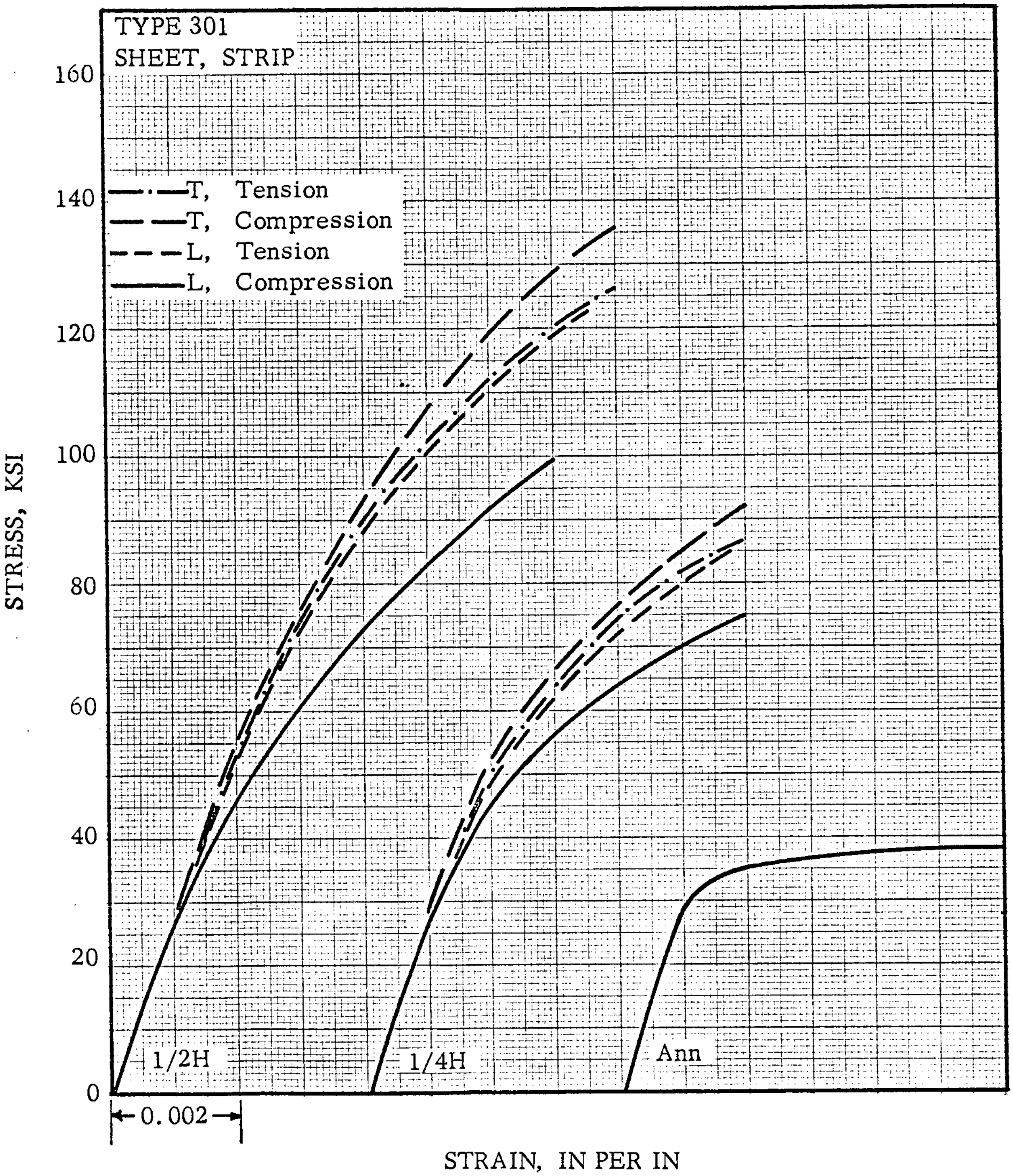

FIG. 7.4121 STRESS-STRAIN CURVES FOR SHEET AND STRIP COLD ROLLED TO 1/4 HARD AND 1/2 HARD CONDITIONS

(Ref. 7.10)

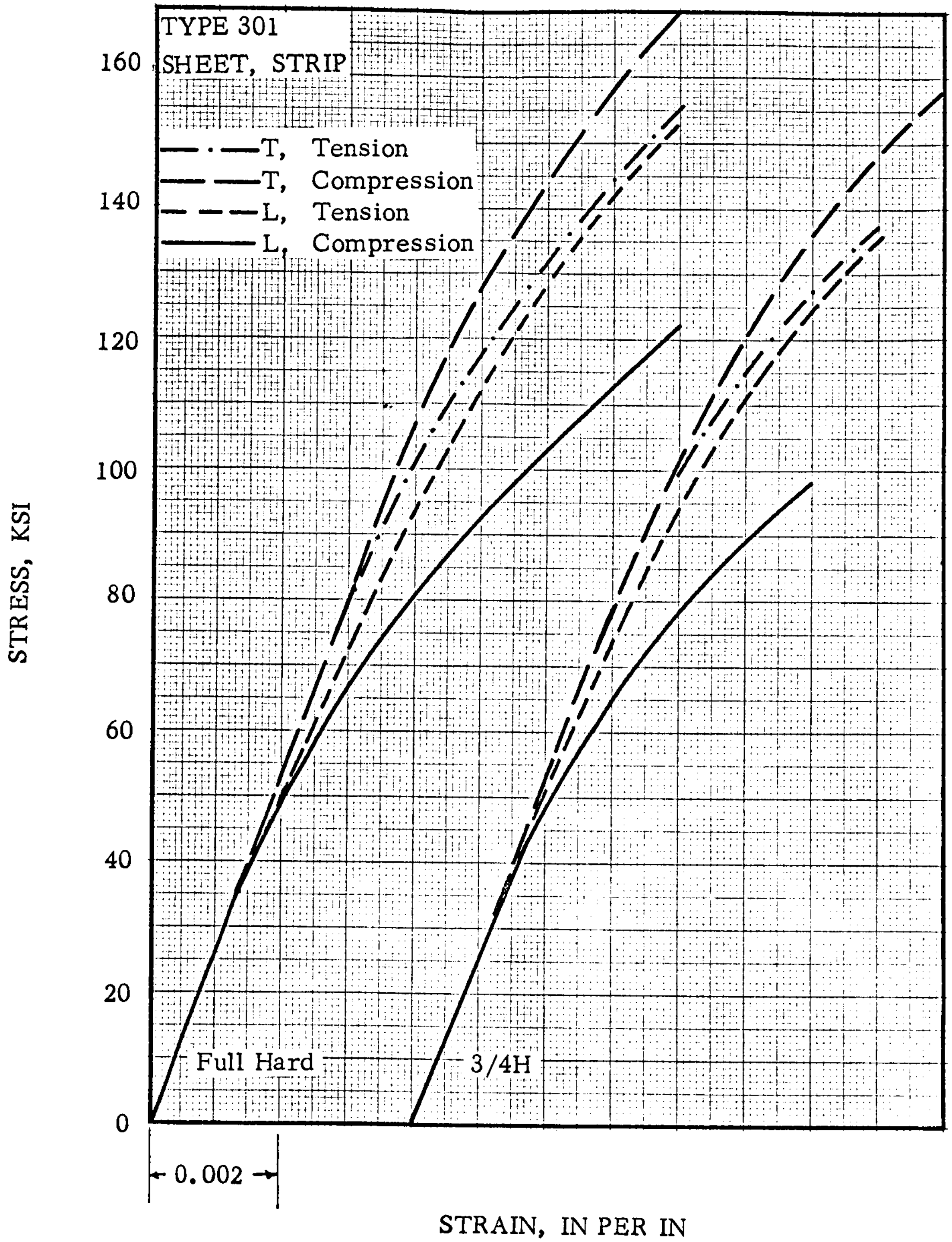

FIG. 7.4122 STRESS-STRAIN CURVES FOR SHEET AND STRIP COLD ROLLED TO 3/4 HARD AND FULL HARD CONDITIONS (Ref. 7.10)

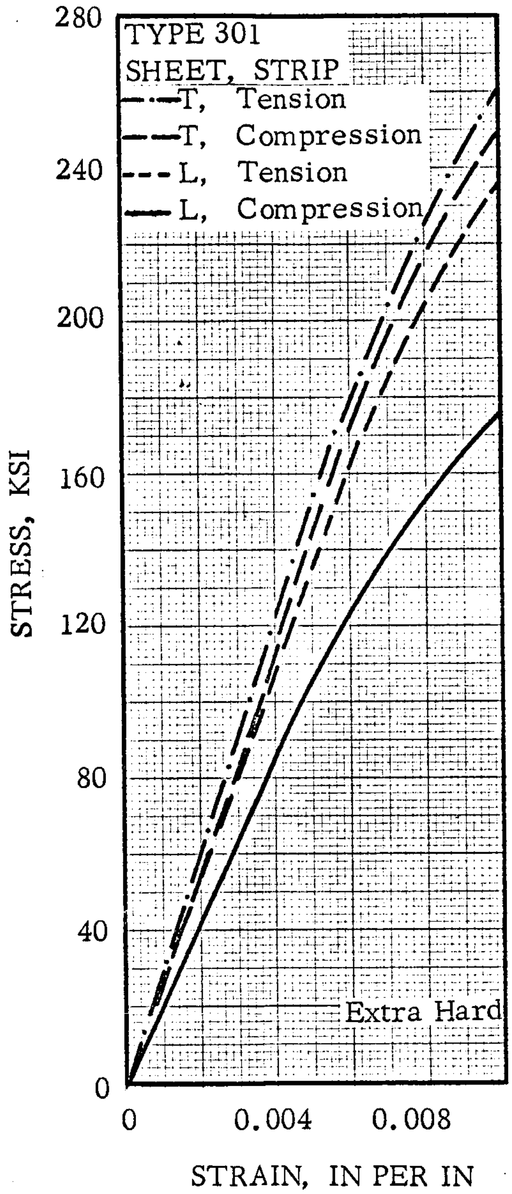

FIG. 7.4123 STRESS-STRAIN CURVES FOR SHEET AND STRIP COLD ROLLED TO EXTRA HARD TEMPER

(Ref. 7.7)

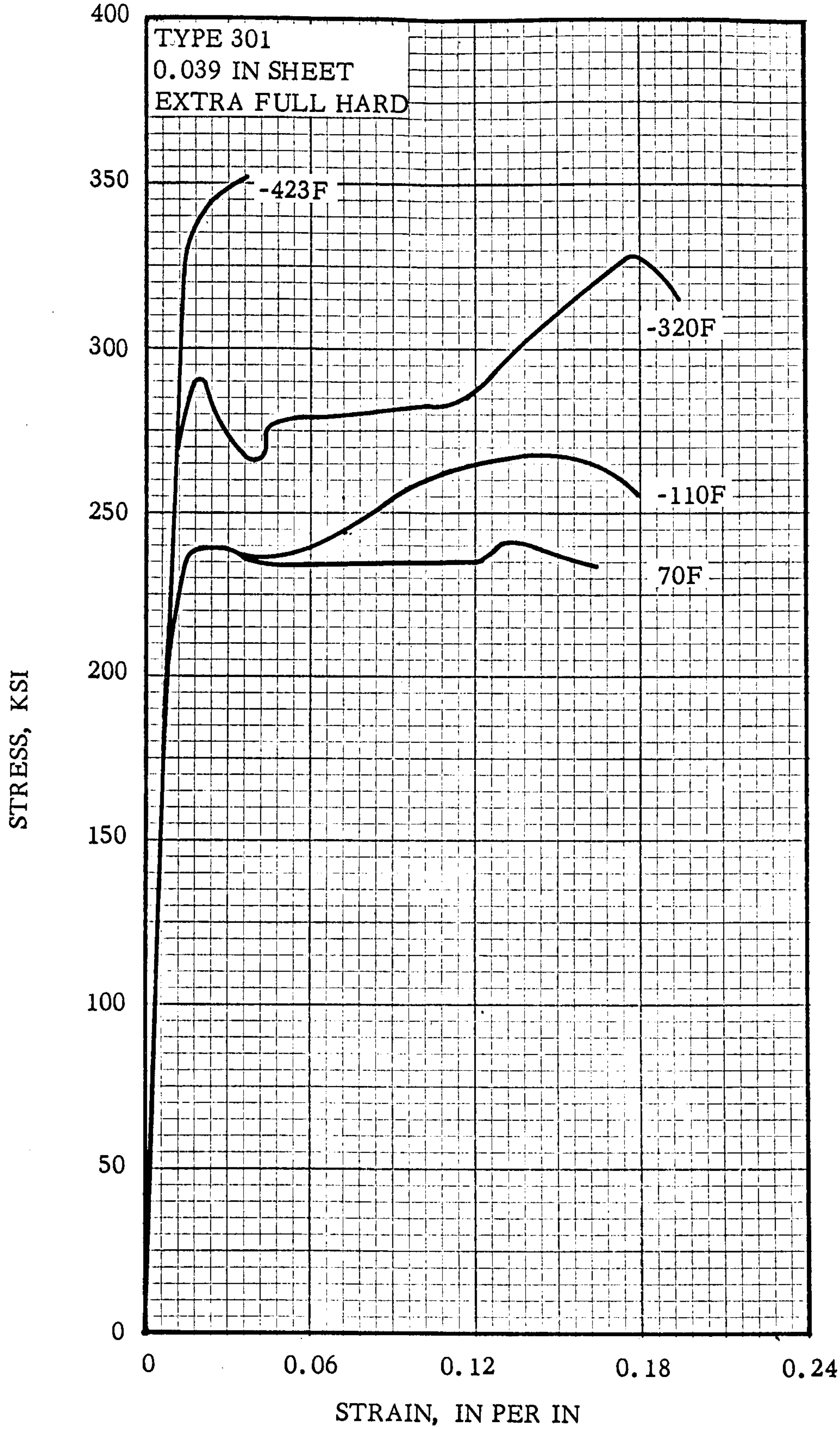

FIG. 7.4124 STRESS-STRAIN CURVES FOR SHEET IN EXTRA FULL HARD CONDITION AT LOW TEMPERATURES (Ref. 7.8)

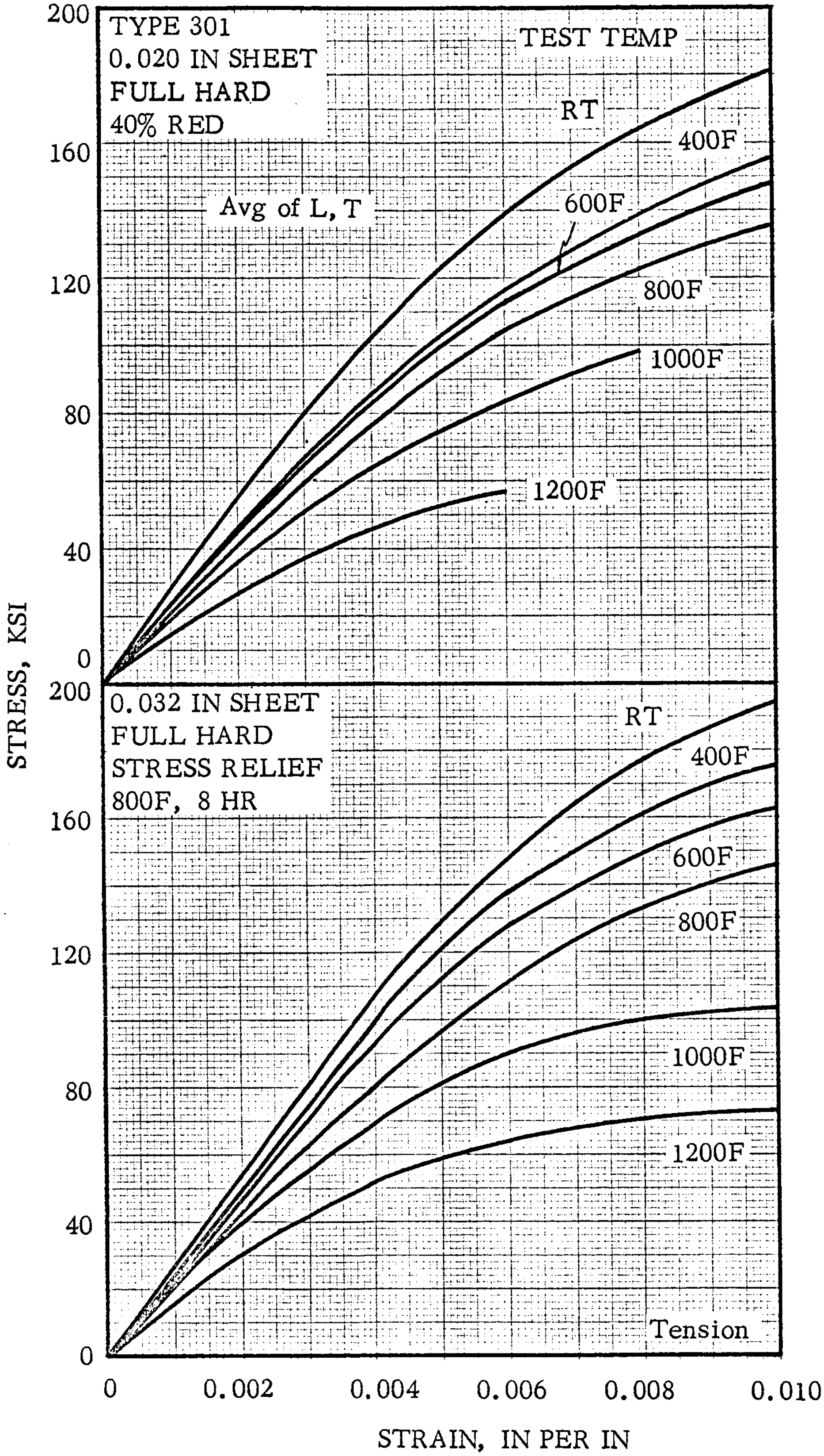

FIG. 7.4125 STRESS-STRAIN CURVES FOR TYPE 301 FULL HARD AND FULL HARD STRESS-RELIEVED SHEET AT ROOM AND ELEVATED TEMPERATURES

(Ref. 7.7)

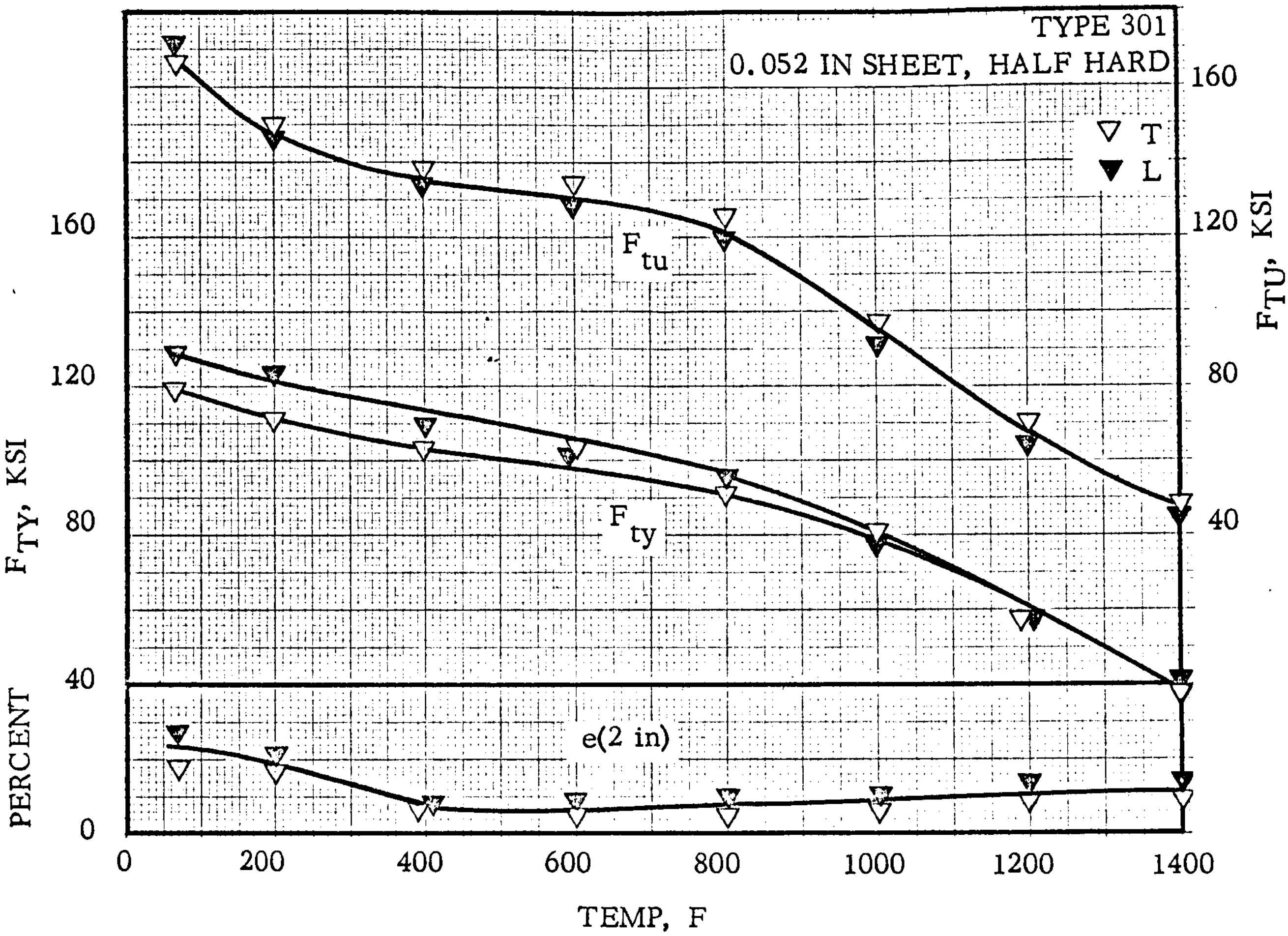

FIG. 7.4131 EFFECT OF TEST TEMPERATURE ON TENSILE PROPERTIES OF TYPE 301 HALF HARD SHEET

(Ref. 7.7)

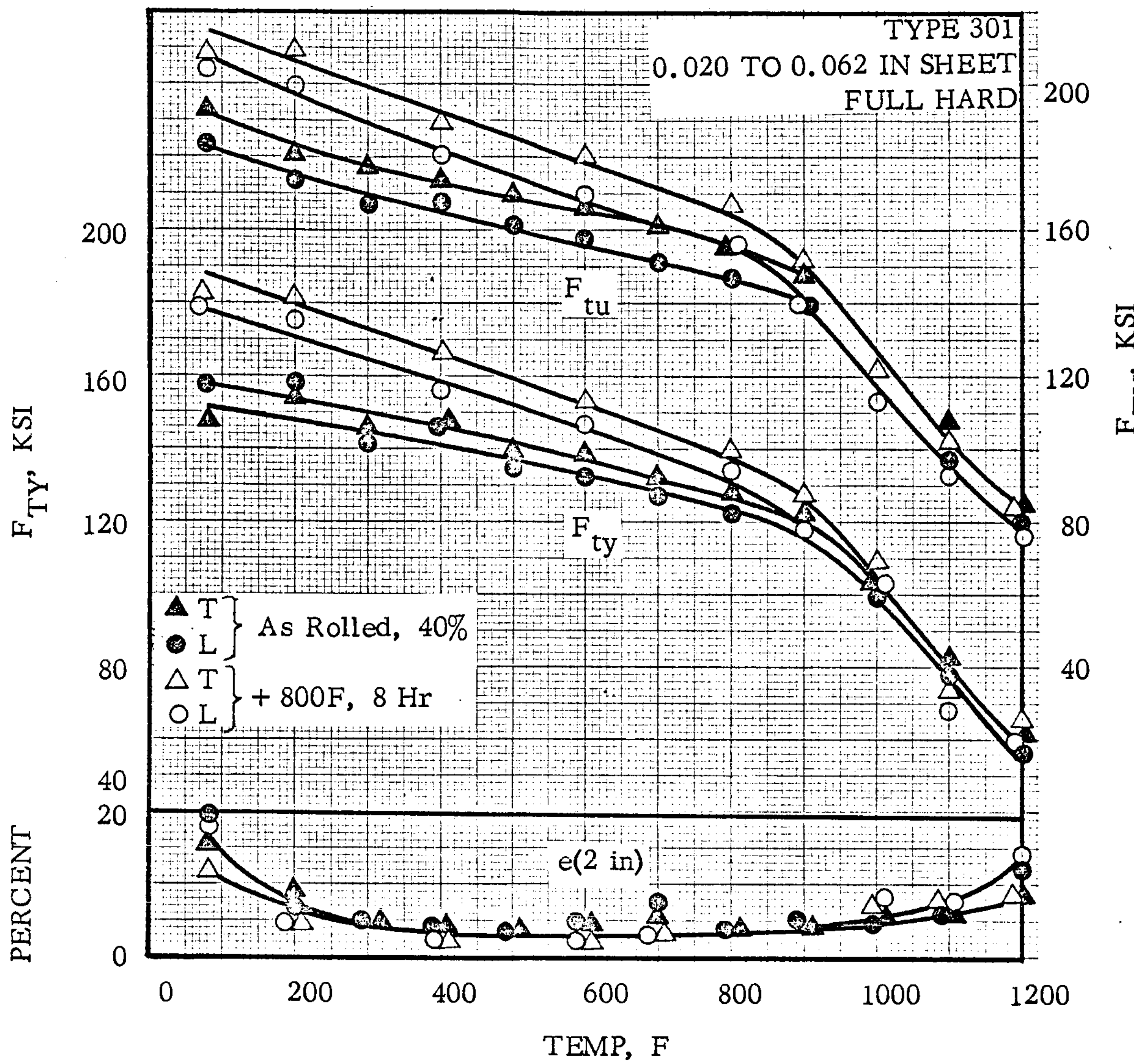

FIG. 7.4132 EFFECT OF TEST TEMPERATURE, TEST DIRECTION AND STRESS RELIEF ON TENSILE PROPERTIES OF TYPE 301 FULL HARD SHEET

(Ref. 7.7)

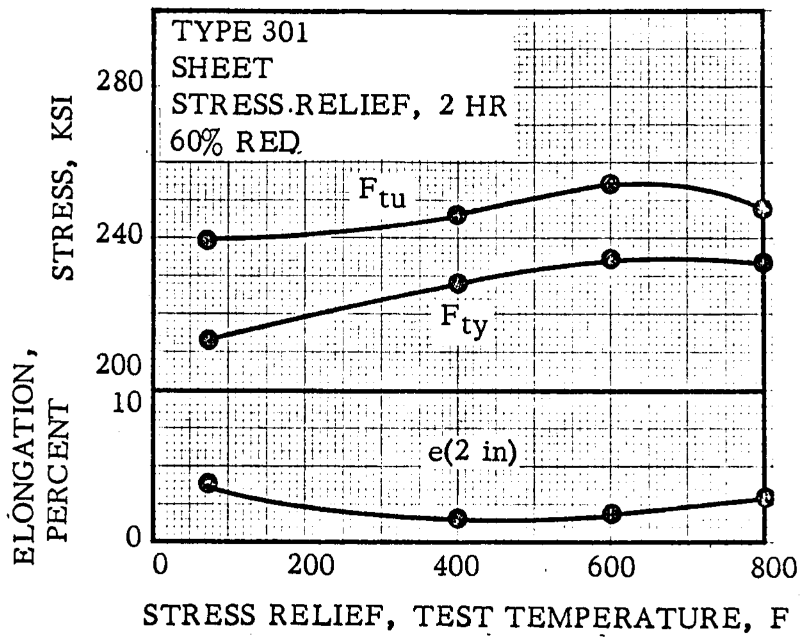

FIG. 7.4133 EFFECT OF STRESS RELIEF TEMPERATURE ON TENSILE PROPERTIES OF 60 PERCENT REDUCED SHEET

(Ref. 7.13)

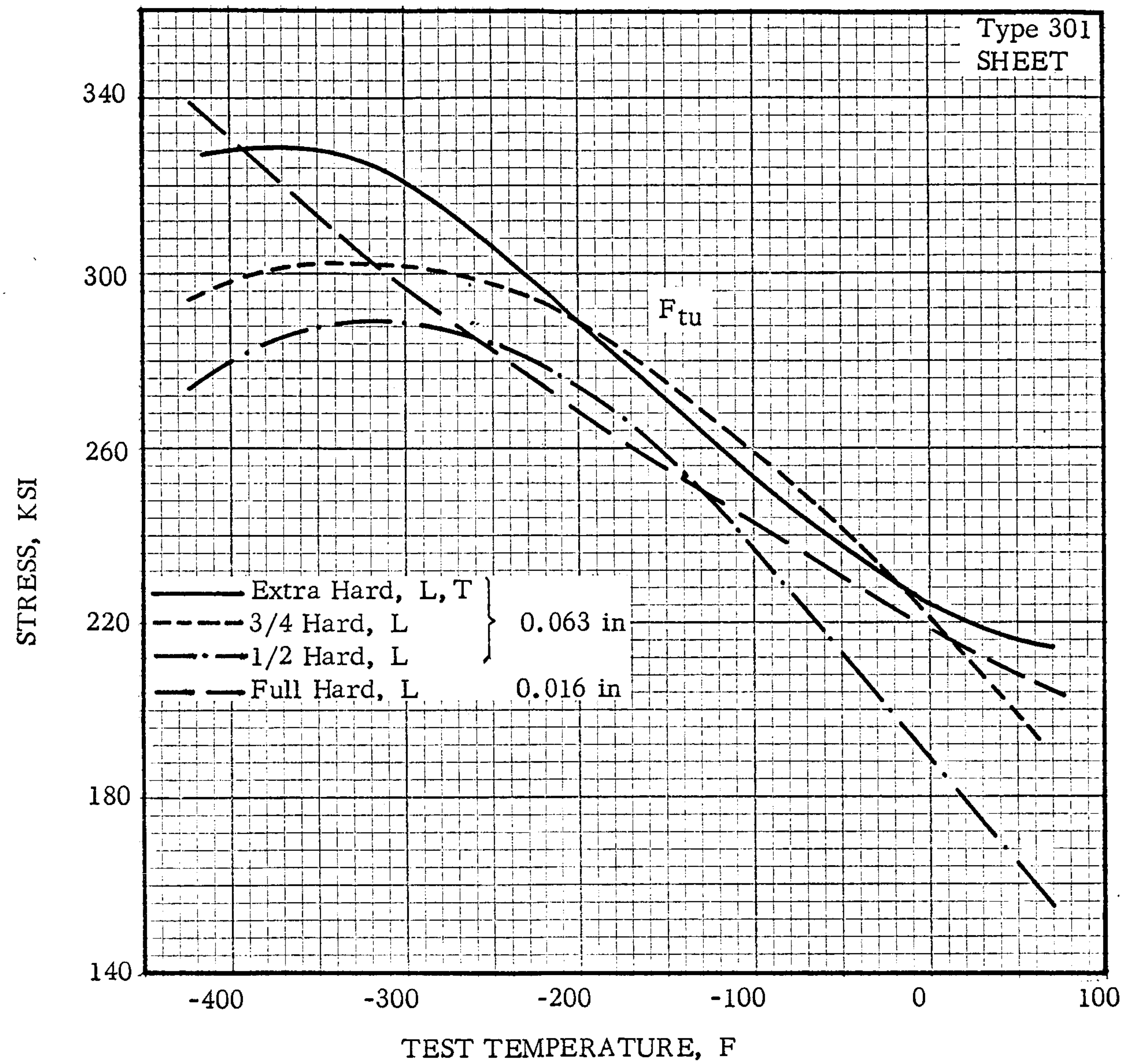

FIG. 7.4134 TENSILE STRENGTH OF SHEET IN VARIOUS CONDITIONS AT LOW TEMPERATURES

(Ref. 7.8)

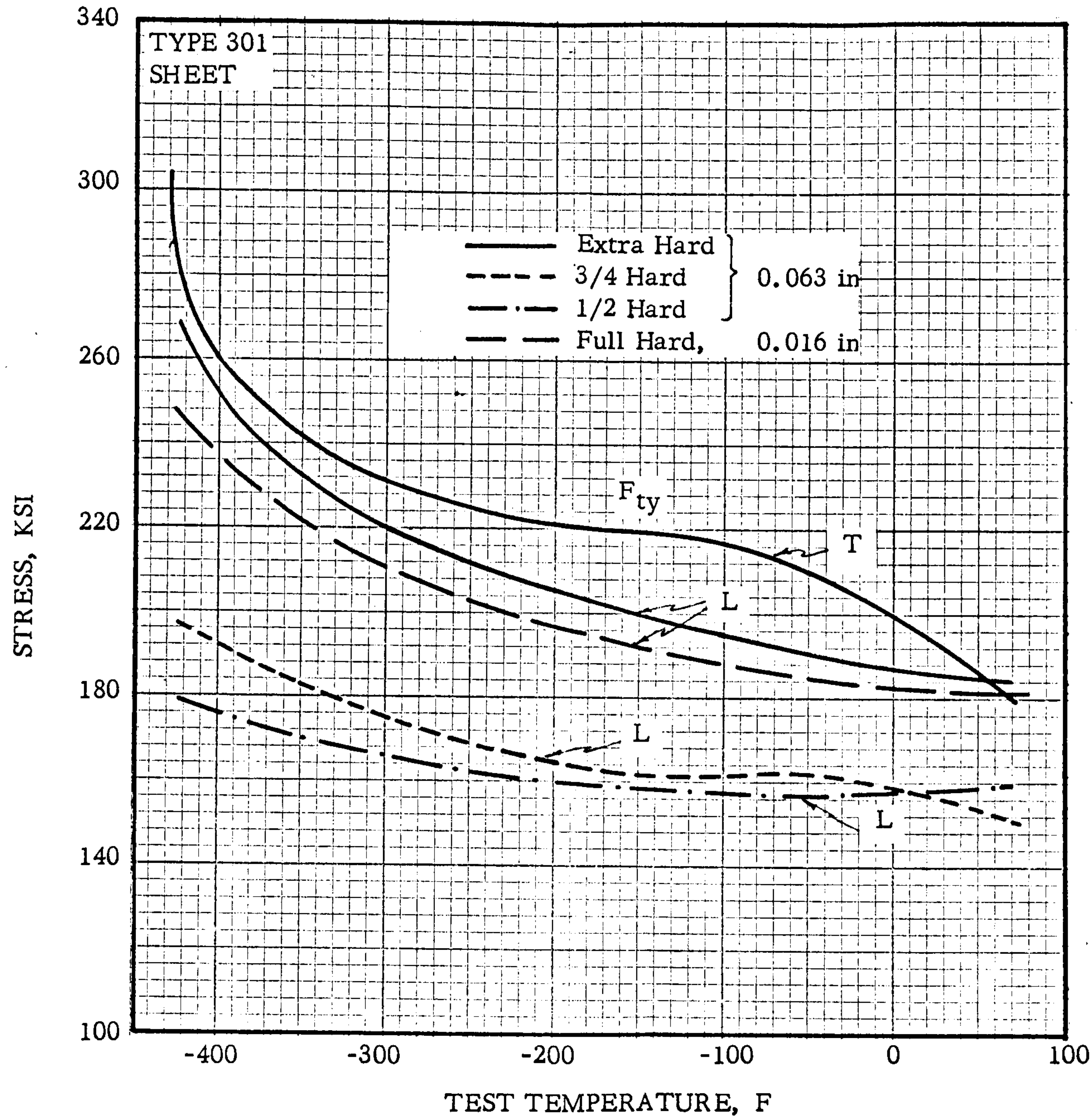

FIG. 7.4135 YIELD STRENGTH OF SHEET IN VARIOUS CONDITIONS AT LOW TEMPERATURES

(Ref. 7.8)

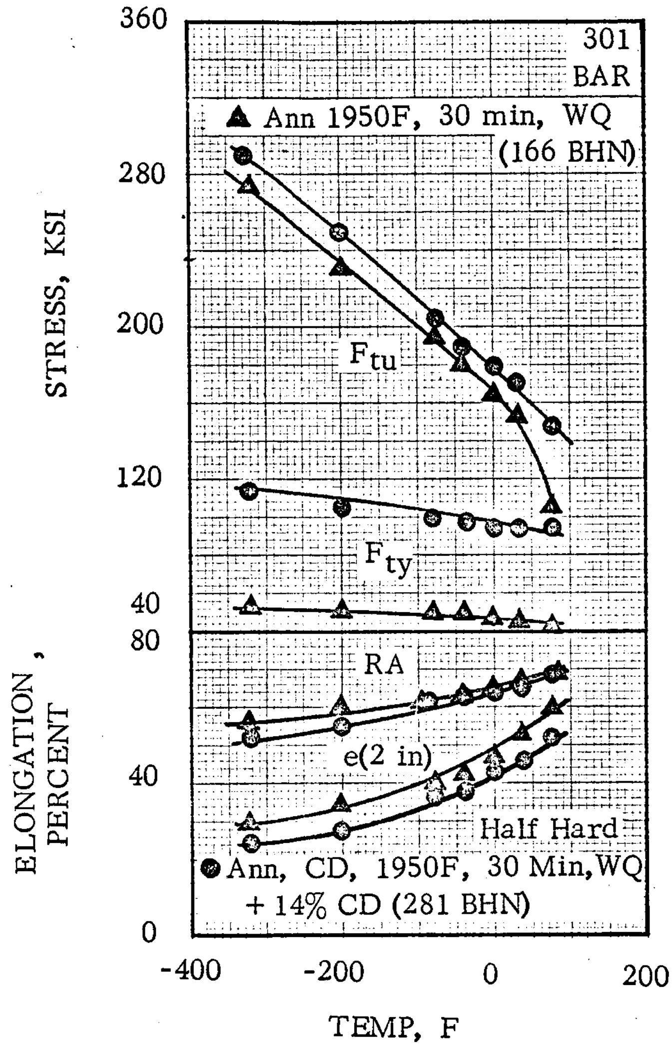

FIG. 7.4136 EFFECT OF ROOM AND LOW TEMPERATURE ON TENSILE PROPERTIES OF ANNEALED AND HALF-HARD BAR

(Ref. 7.19)

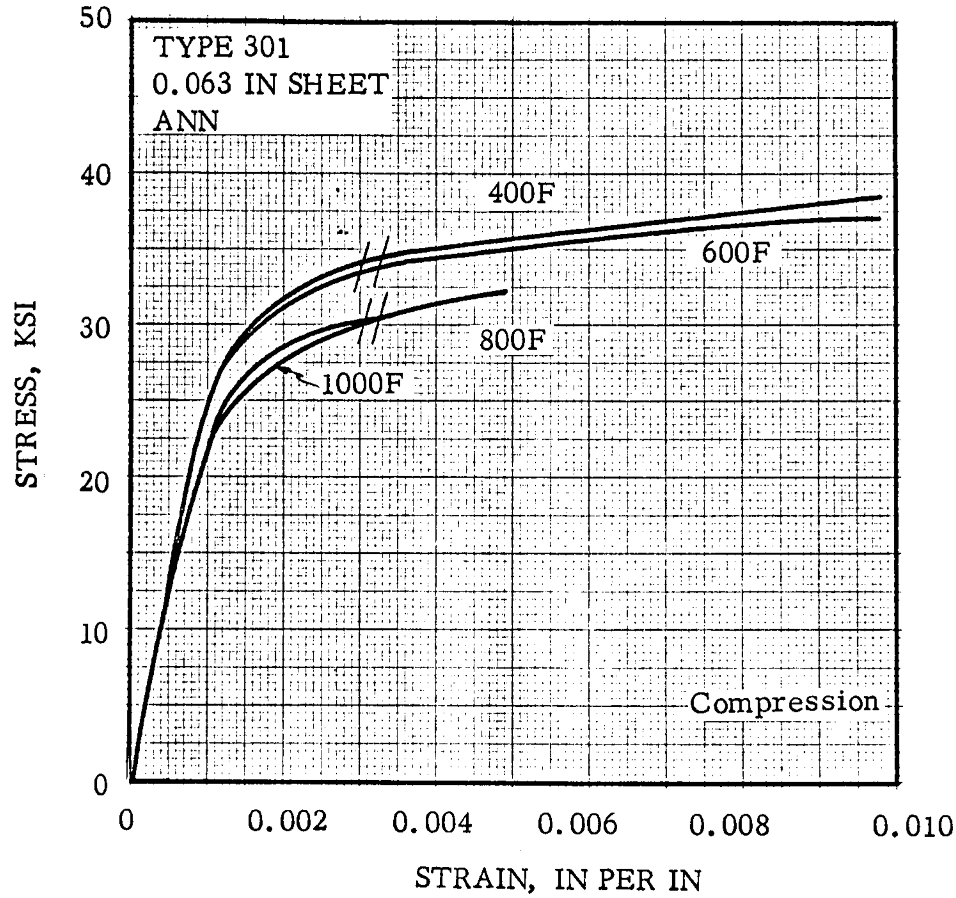

FIG. 7.4221 STRESS-STRAIN CURVES IN COMPRESSION FOR TYPE 301 ANNEALED SHEET AT ELEVATED TEMPERATURES

(Ref. 7.15)

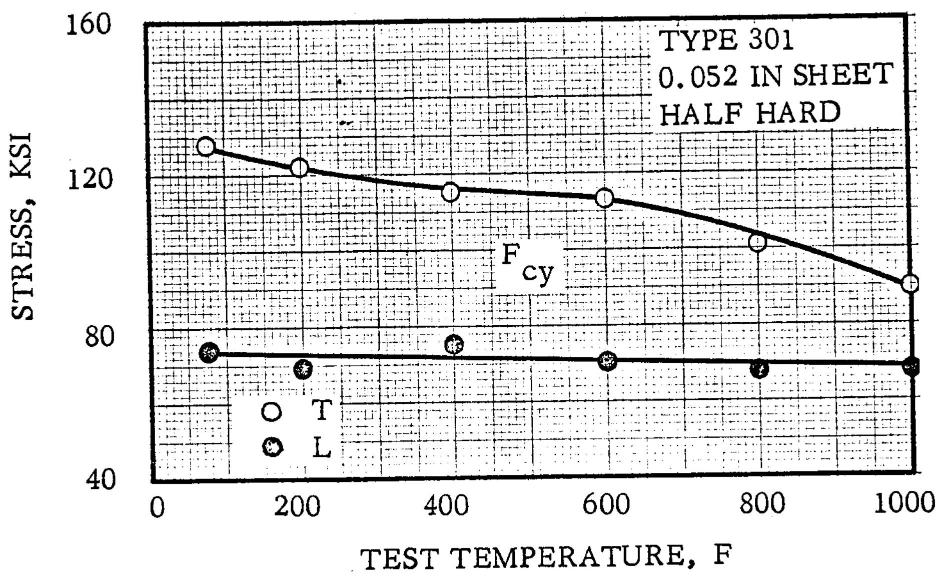

FIG. 7.4231 EFFECT OF TEST TEMPERATURE AND TEST DIRECTION ON COMPRESSIVE YIELD STRENGTH OF TYPE 301 HALF HARD SHEET

(Ref. 7.7)

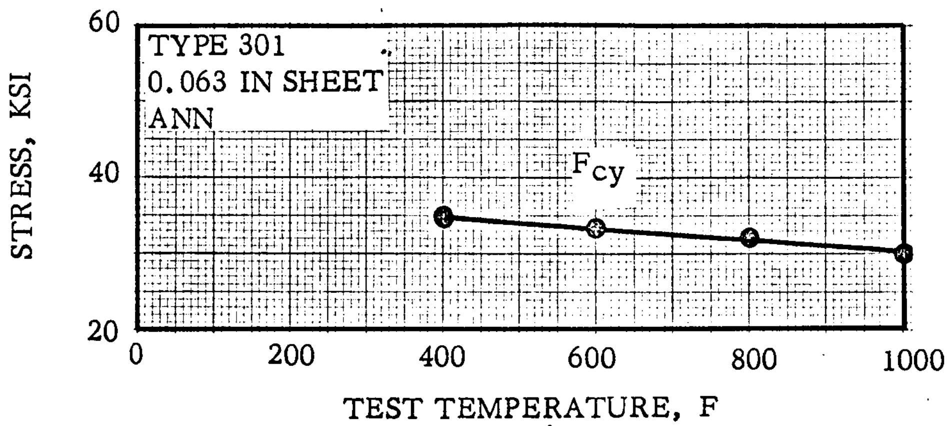

FIG. 7.4232 EFFECT OF TEST TEMPERATURE ON COMPRESSIVE YIELD STRENGTH OF TYPE 301 ANNEALED SHEET

(Ref. 7.15)

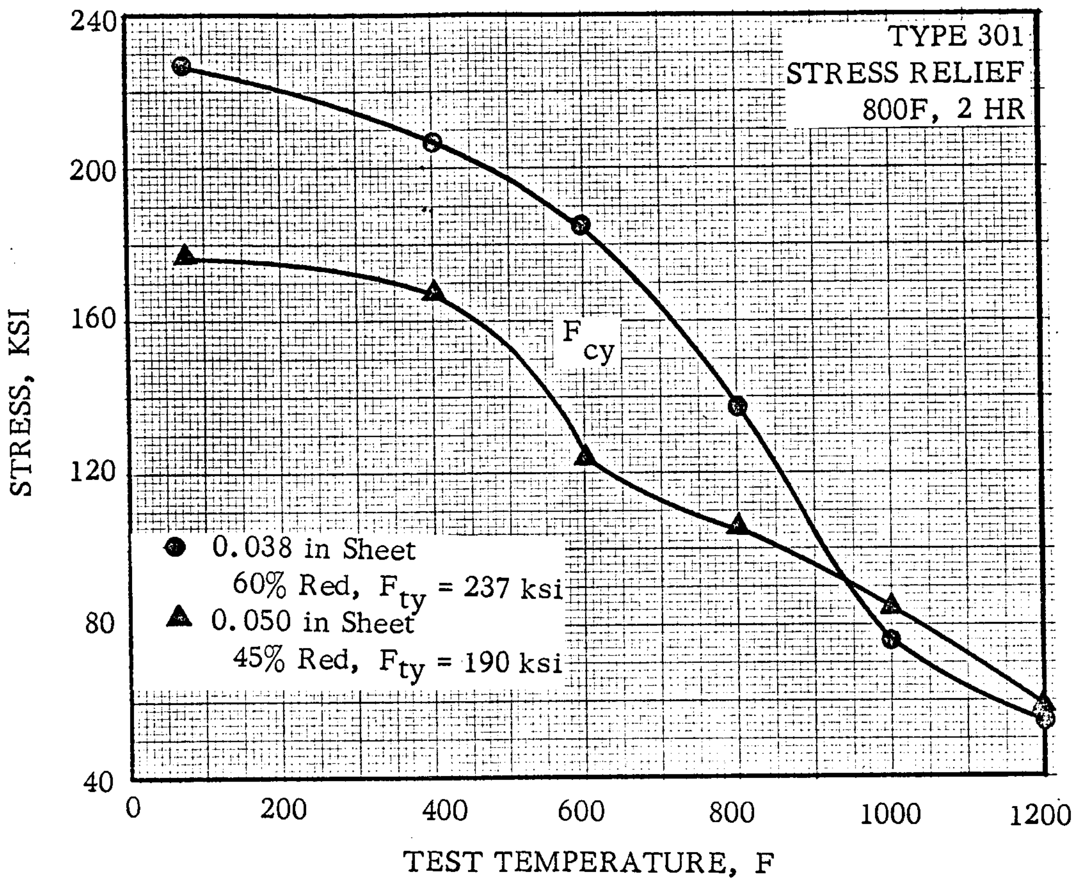

FIG. 7.4233 EFFECT OF TEST TEMPERATURE ON COMPRESSIVE YIELD STRENGTH OF 45 PERCENT AND 60 PERCENT REDUCED SHEET

(Ref. 7.13)

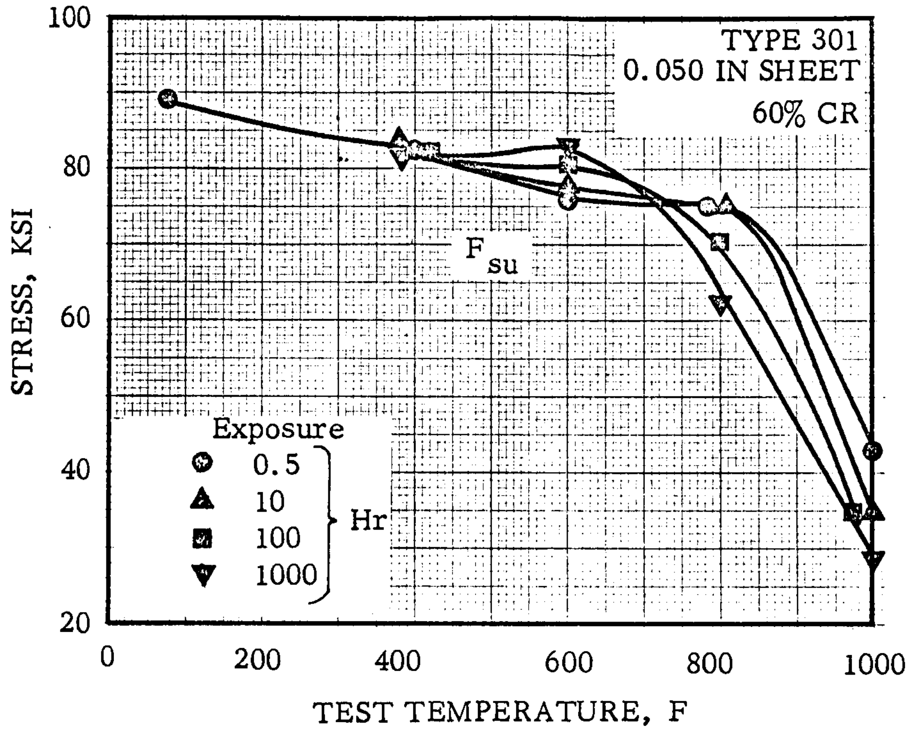

FIG. 7.442 EFFECT OF TEST TEMPERATURE AND EXPOSURE TIME ON SHEAR STRENGTH OF 60 PERCENT COLD REDUCED SHEET

(Ref. 7.16)

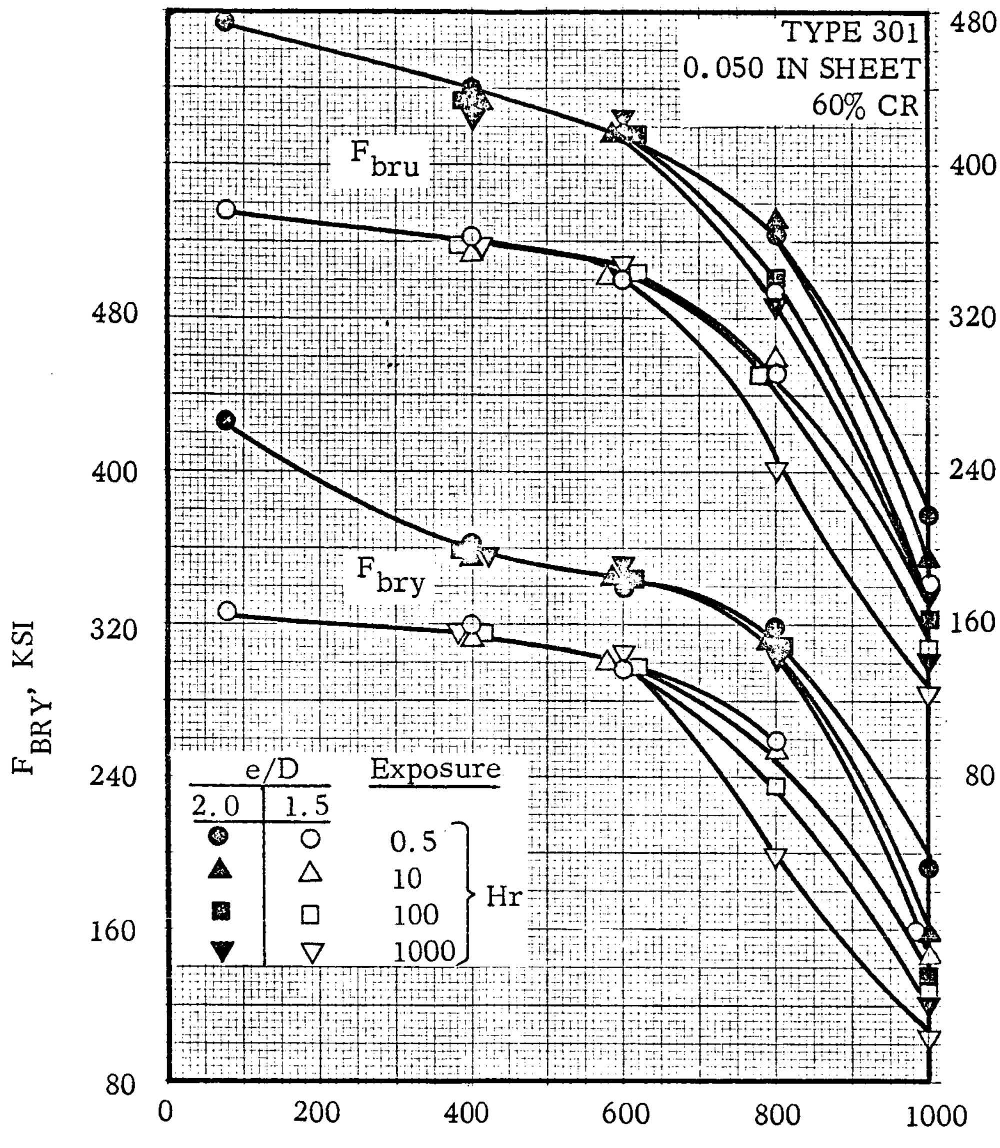

FIG. 7.452 EFFECT OF TEST TEMPERATURE AND EXPOSURE TIME ON BEARING PROPERTIES OF 60 PERCENT COLD REDUCED SHEET

(Ref. 7.16)

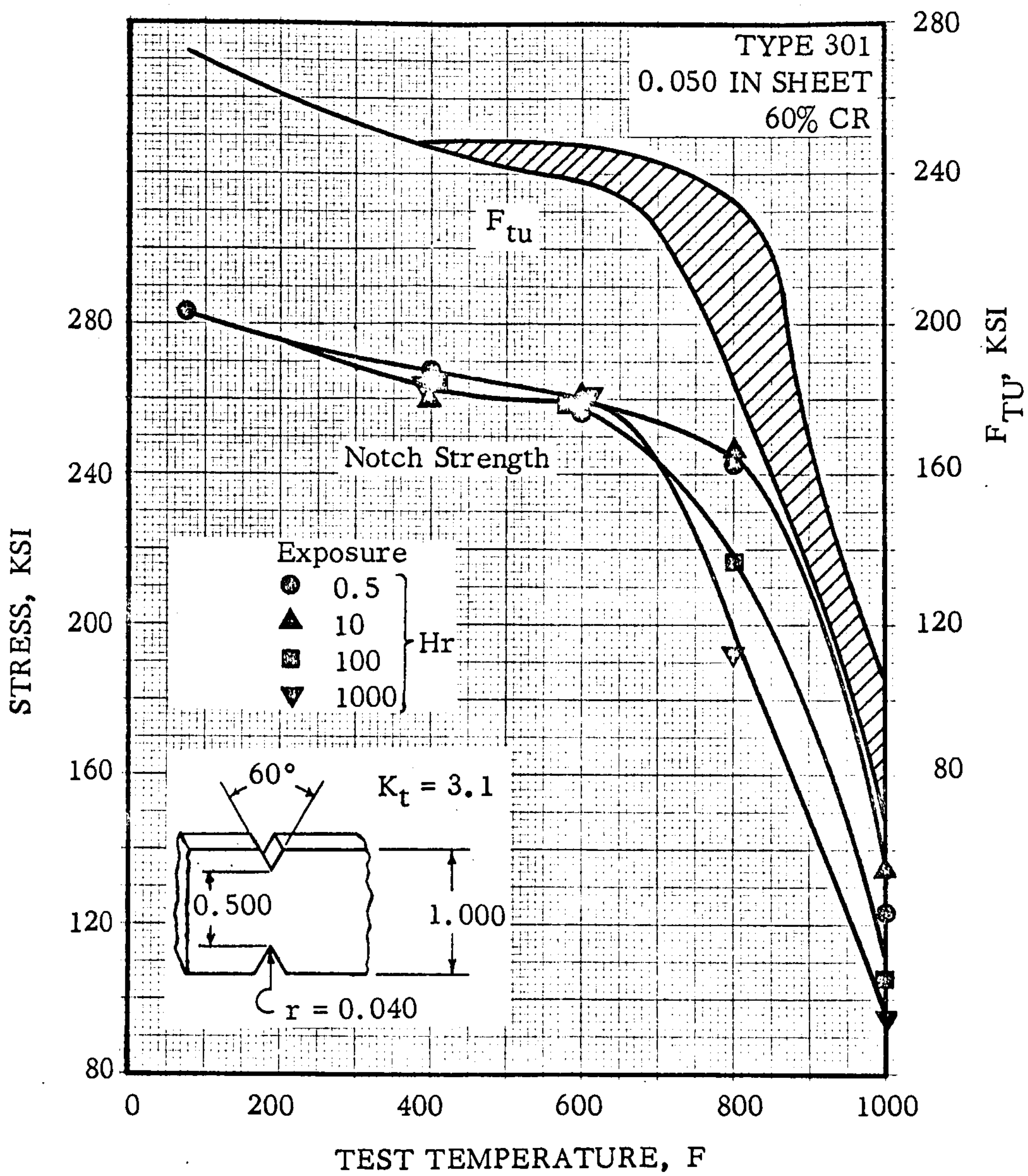

FIG. 7.4611 EFFECT OF TEST TEMPERATURE AND EXPOSURE TIME ON NOTCH STRENGTH OF 60 PERCENT COLD REDUCED SHEET

(Ref. 7.16)

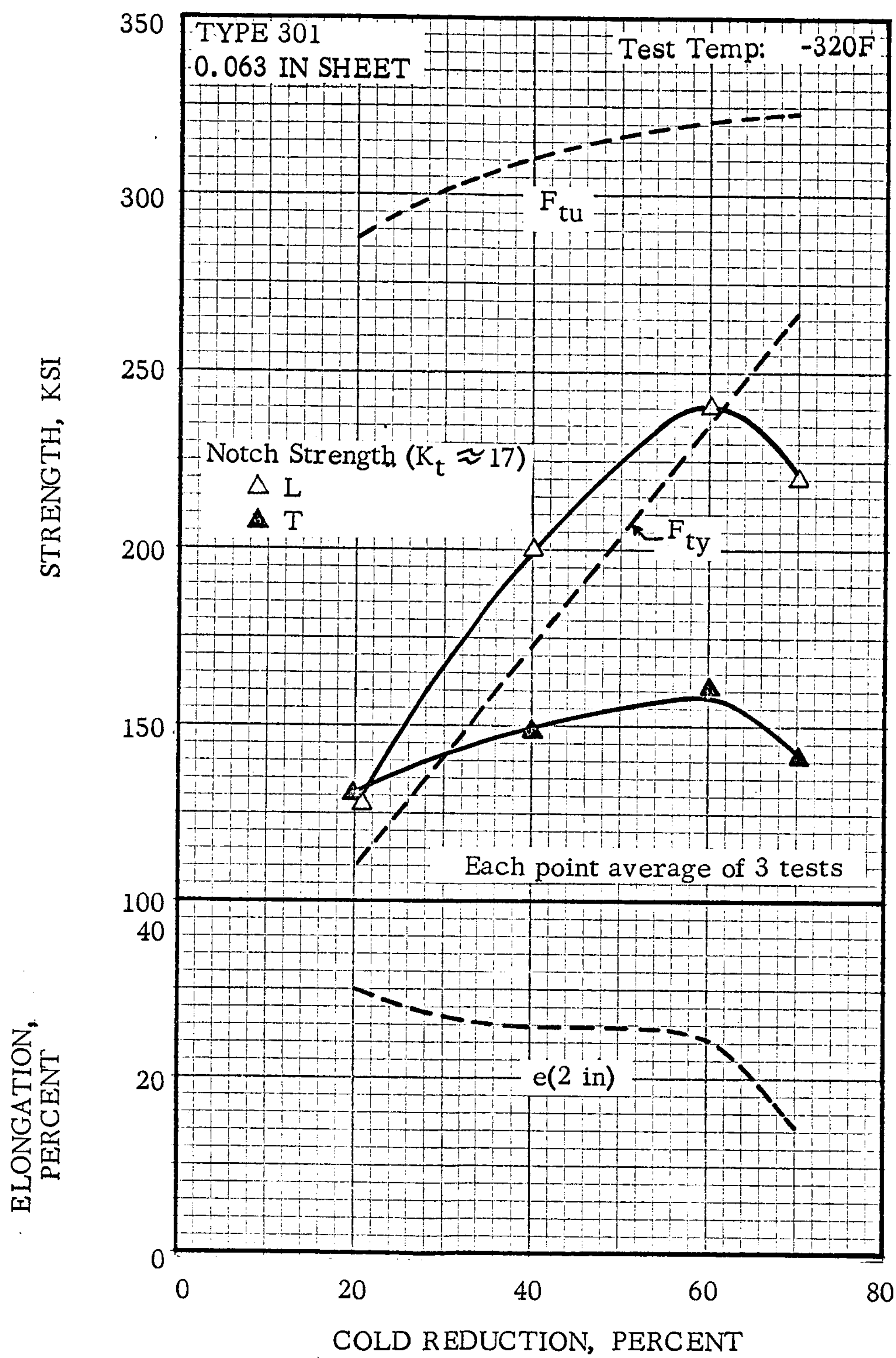

FIG. 7.4612 EFFECT OF COLD REDUCTION AND TEST DIRECTION ON SHARP NOTCH STRENGTH OF SHEET

(Ref. 7.17)

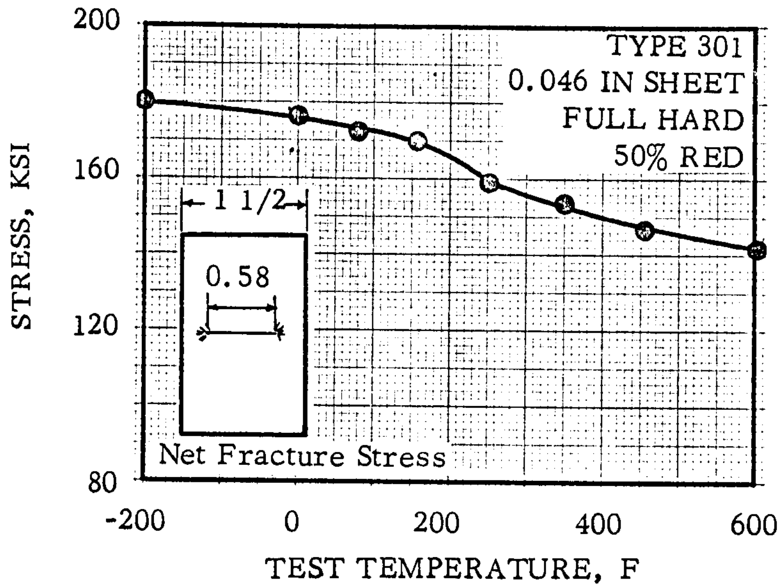

FIG. 7.4613 EFFECT OF TEST TEMPERATURE ON NET FRACTURE STRESS OF FULL HARD SHEET

(Ref. 7.18)

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7.13 "USS 301, A Standard AISI Type Stainless Steel Cold Reduced to Higher Properties for Aircraft and Missiles", U. S. Steel Corp., (June 1959)

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7.18 J. D. Morrison and J. R. Kattus, "An Investigation of Methods for Determining Crack Propagation Resistance of High Strength Alloys", Southern Research Inst., (January 1961)

7.19 Alloy Digest, "AISI Type 301", Filing Code SS-54, Engineering Alloys Digest, Inc., (April 1957)

CHAPTER 8

DYNAMIC AND TIME DEPENDENT PROPERTIES

8.1 General. Type 301 has good dynamic and time dependent properties. In the annealed condition the alloy exhibits good impact strength down to cryogenic temperatures. The alloy can be used at moderately elevated temperatures because of its excellent creep and rupture properties. It has good structural stability for long time use at temperatures up to 800F. When held in the temperature range from 800 to 1600F, however, carbides are precipitated which may lower the corrosion resistance of the alloy. Also, exposure of cold reduced material to temperatures above 900F results in a reduction in room temperature properties, (Refs. 8.1, 8.2 and 8.3).

8.2 Specified Properties

8.3 Impact

8.31 Izod impact strength of annealed sheet. 110 ft-lbs, (Ref. 8.4).

8.32 Effect of low temperature on impact strength of annealed plate, Fig. 8.32.

8.33 Effect of room and low temperature on impact strength of annealed and 1/2 hard bar, Fig. 8.33.

8.4 Creep

8.41 Creep and creep rupture curves for Type 301 1/2 hard sheet at 1200 to 1500F, Fig. 8.41.

8.42 Creep rupture curves for Type 301 full hard and stress relieved sheet at 800 to 1200F, Fig. 8.42.

8.43 Creep and creep rupture curves at 800F for full hard sheet, Fig. 8.43.

8.44 Time-temperature-parameters

8.45 Isochronous stress-strain diagrams

8.5 Stability

8.51 Effect of exposure at low temperatures on room temperature tensile properties of extra hard sheet, Fig. 8.51.

8.52 Effect of temperature and exposure time on tensile properties of 60 percent reduced sheet, Fig. 8.52.

8.53 Effect of test temperature and exposure time on shear strength of 60 percent cold reduced sheet, see Fig. 7.442, (Chapter 7).

8.54 Effect of test temperature and exposure time on bearing properties of 60 percent cold reduced sheet, see Fig. 7.452, (Chapter 7).

8.55 Effect of test temperature and exposure time on notch strength of 60 percent cold reduced sheet, see Fig. 7.4611, (Chapter 7).

8.6 <u>Fatigue</u>

8.61 S-N curves in flexure for extra full hard sheet at low temperatures, Fig. 8.61.

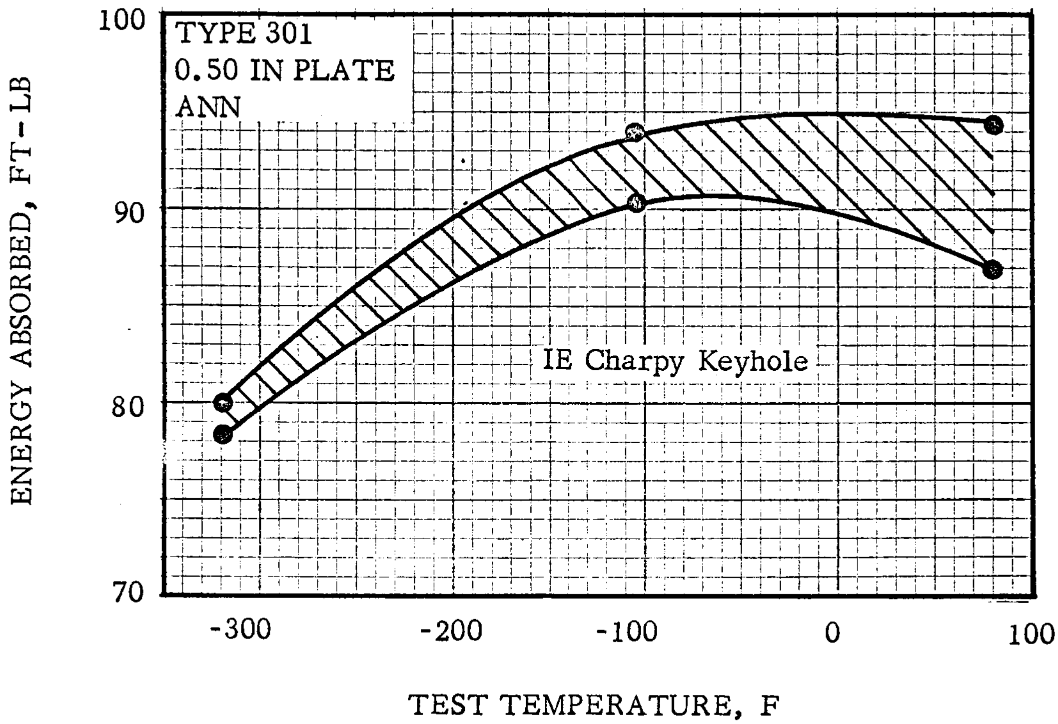


FIG. 8.32 EFFECT OF LOW TEMPERATURE ON IMPACT STRENGTH OF ANNEALED PLATE

(Ref. 8.5)

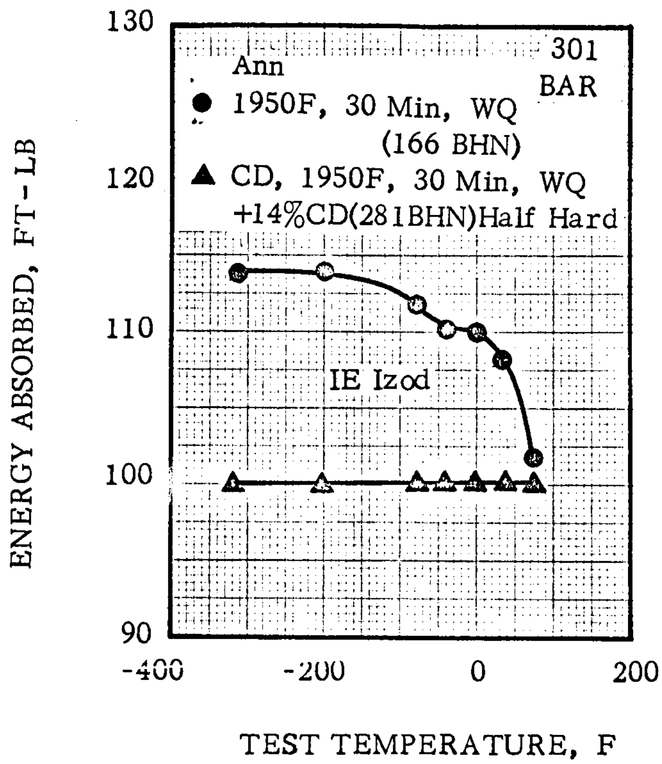


FIG. 8.33 EFFECT OF ROOM AND LOW TEMPERATURE ON IMPACT STRENGTH OF ANNEALED AND HALF HARD BAR

(Ref. 8.1)

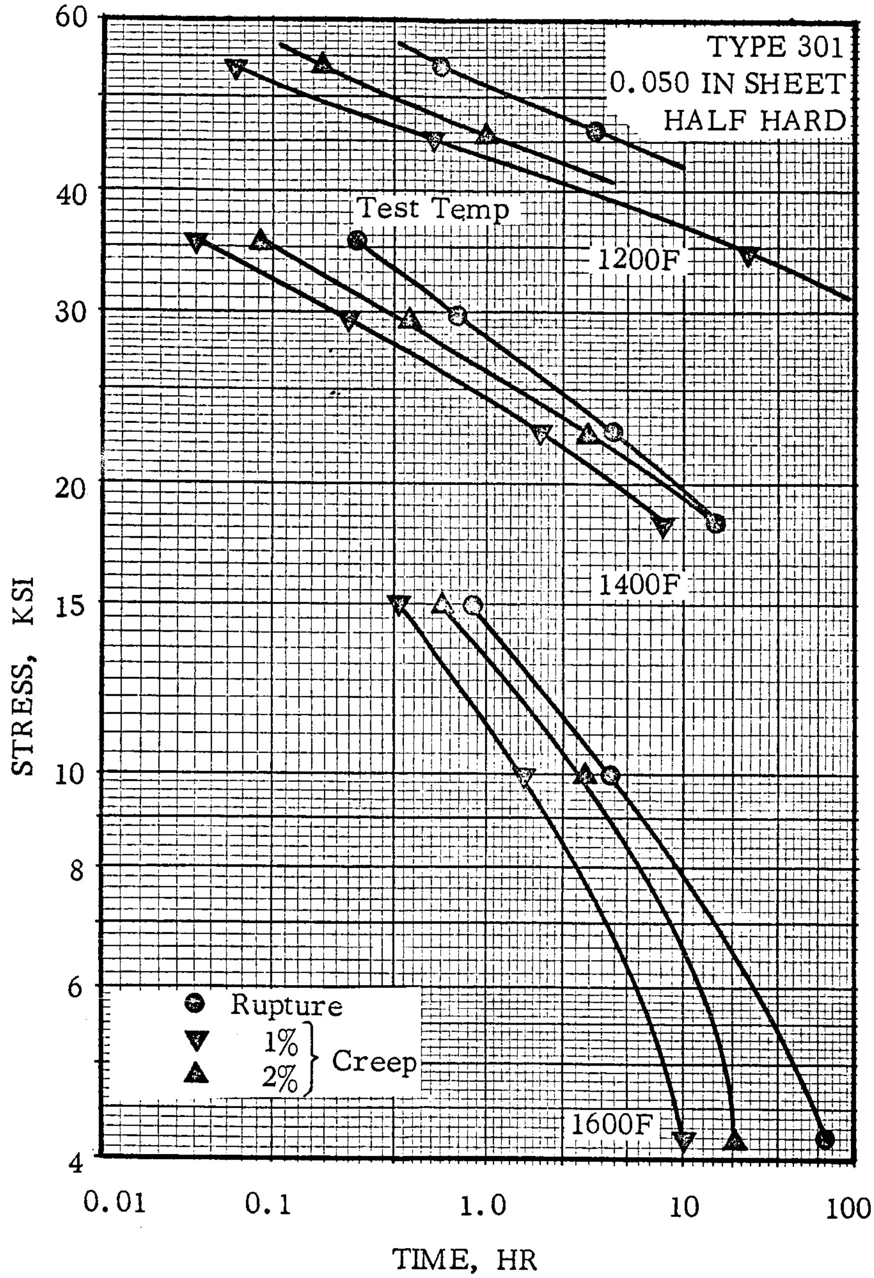


FIG. 8.41 CREEP AND CREEP RUPTURE CURVES FOR TYPE 301 HALF HARD SHEET AT 1200F TO 1500F

(Ref. 8.6)

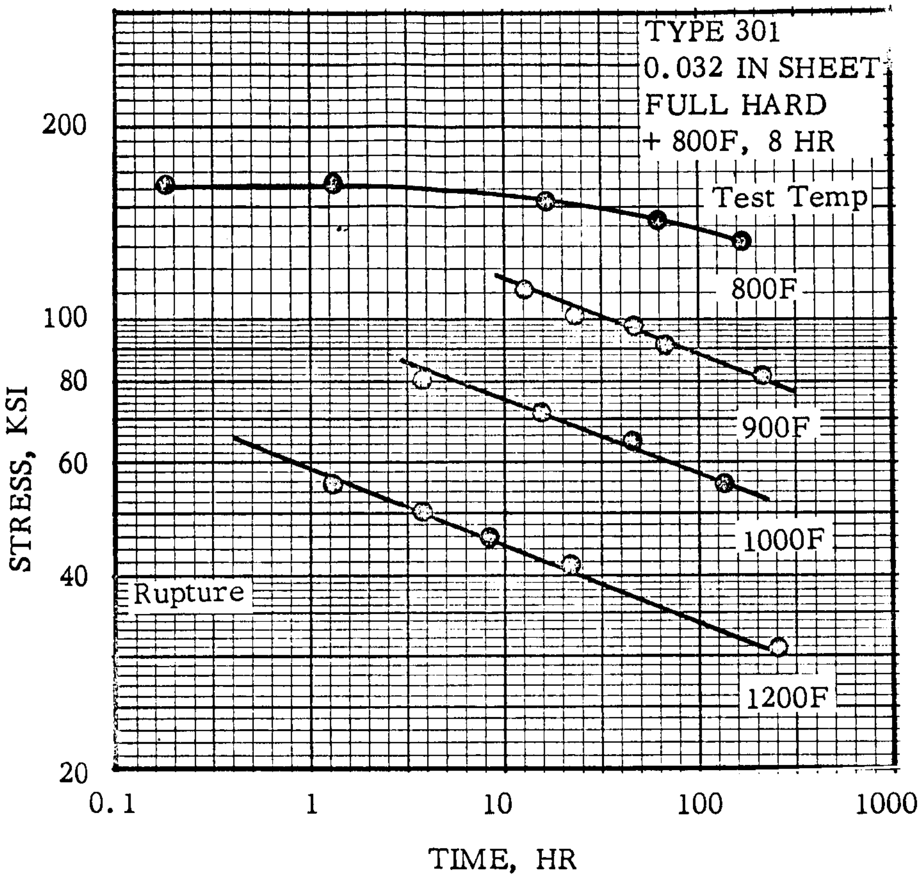


FIG. 8.42 CREEP RUPTURE CURVES FOR TYPE 301 FULL HARD AND STRESS RELIEVED SHEET AT 800 TO 1200F (Ref. 8.7)

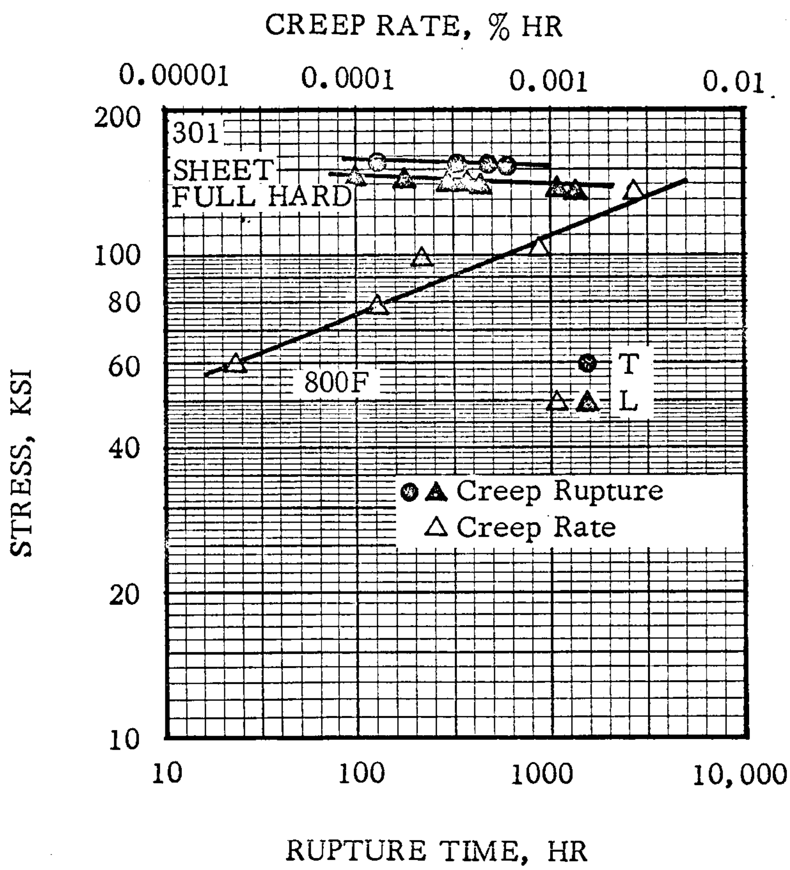


FIG. 8.43 CREEP AND CREEP RUPTURE CURVES AT 800F FOR FULL HARD SHEET

(Ref. 8.1)

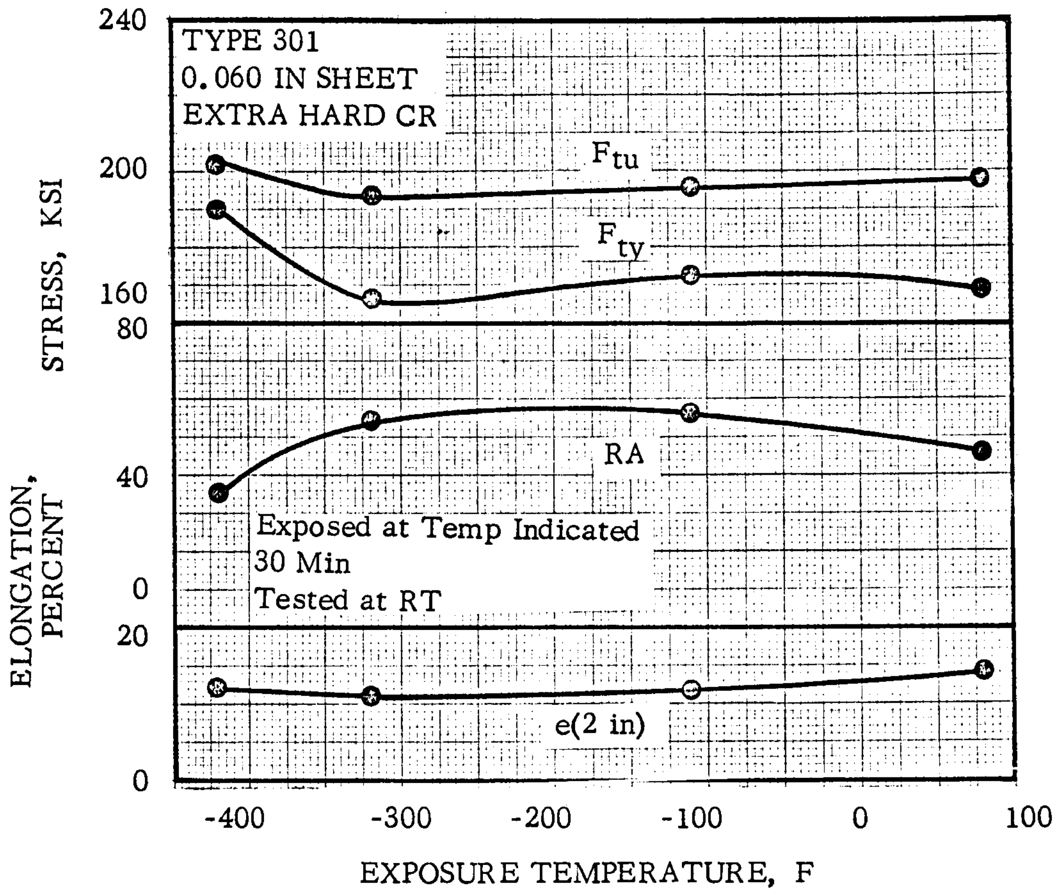


FIG. 8.51 EFFECT OF EXPOSURE AT LOW TEMPERATURE ON ROOM TEMPERATURE TENSILE PROPERTIES OF EXTRA HARD COLD ROLLED SHEET

(Ref. 8.10)

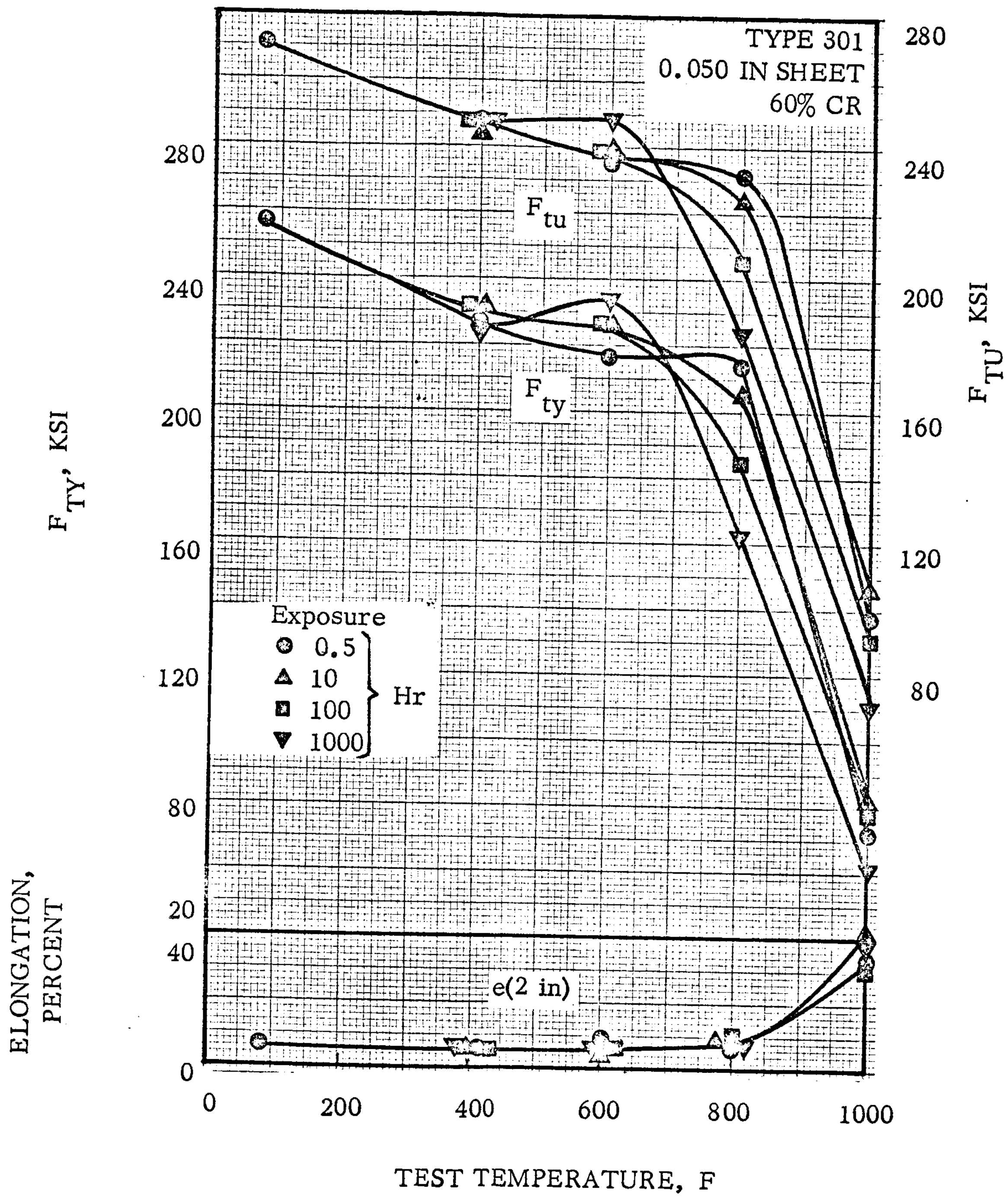


FIG. 8.52 EFFECT OF TEST TEMPERATURE AND EXPOSURE TIME ON TENSILE PROPERTIES OF 60 PERCENT COLD REDUCED SHEET

(Ref. 8.9)

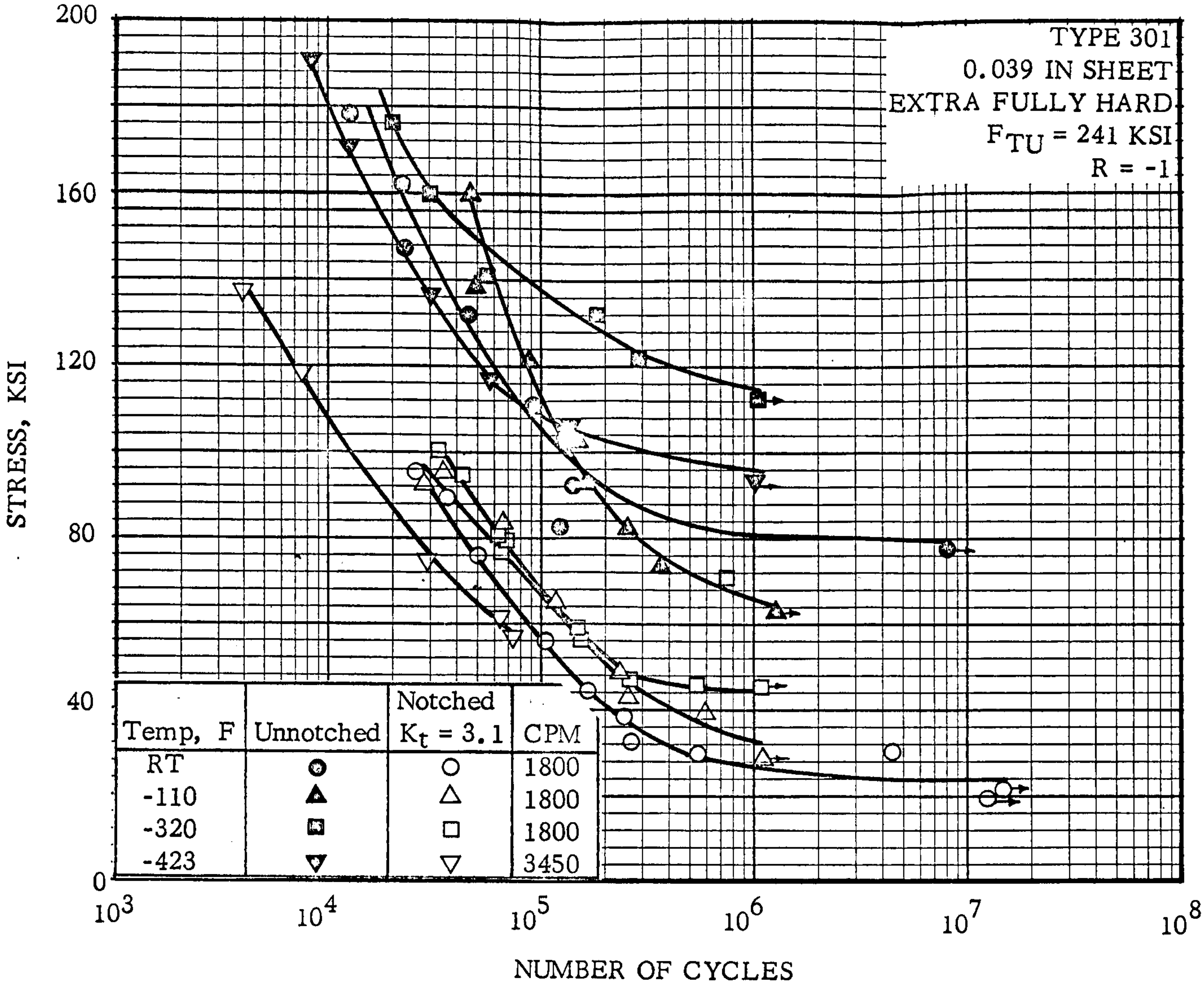
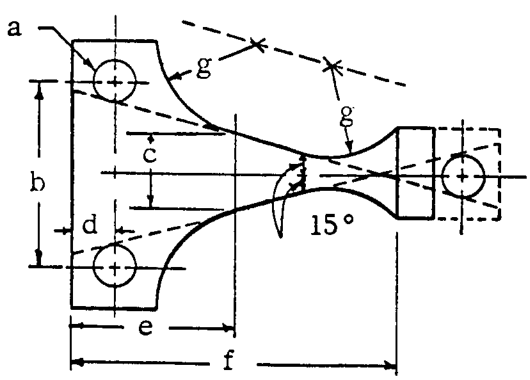


FIG. 8.61 S-N CURVES IN FLEXURE FOR EXTRA FULLY HARD SHEET AT LOW TEMPERATURES

(Ref. 8.8)



a = 0.187 - 0.188 IN DIA·(3 HOLES)
b= 0.808 ± 0.002 IN
c = 0.378 ± 0.002 IN
d = 0.-47 ± 0.002 IN
e = 0.700 ± 0.002 IN
f = 1.400 ± 0.002 IN
g = 0.40

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8.8 R. J. Favor et al., "Investigation of Fatigue Behavior of Certain Alloys in the Temperature Range of Room Temperature to -423F", WADD-TR-60-123, Battelle Memorial Inst., (June 1961)

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8.10 L. P. Rue, et al., "The Evaluation of the Effects of Very Low Temperatures on the Properties of Aircraft and Missile Metals", WADD-TR-60-254, (February 1960)

CHAPTER 9

PHYSICAL PROPERTIES

9.1 Density, (ρ) at room temperature
0.286 lb/in^3
7.83 gr/cm^3, (Refs. 9.1 and 9.2).

9.2 Thermal Properties
9.21 Thermal conductivity (K), Fig. 9.21.
9.22 Thermal expansion (α), Fig. 9.22.
9.23 Specific heat (c_p), Fig. 9.23
9.24 Thermal diffusivity, Fig. 9.24.

9.3 Electrical Properties
9.31 Electrical resistivity, Fig. 9.31.

9.4 Magnetic Properties. This alloy is nonmagnetic in the annealed condition but becomes magnetic when cold worked. The degree of magnetization increases with decreasing nickel content, (Ref. 9.2).
9.41 Permeability, (at 200 oersteds)
Annealed, 1.003
10% CW, 1.10
60% CW, 20.0 (approx).

9.5 Nuclear Properties. The effects of exposure to high intensity nuclear radiation is generally as follows:

a) Magnetic susceptibility is increased, depending on material condition and irradiation variables such as total flux and temperature.

b) Tensile strength yield strength and hardness of annealed alloy are increased, elongation is usually decreased.

c) Austenitic stainless steels retain their high impact strength after irradiation.

9.51 Effect of high intensity nuclear radiation on tensile properties and hardness, Table 9.51.
9.52 Effect of irradiation below 100C (212F) on yield strength, Fig. 9.52.

9.6 Other Physical Properties
9.61 Emissivity, Fig. 9.61.
9.62 Damping capacity

EFFECT OF HIGH INTENSITY NUCLEAR RADIATION ON TENSILE PROPERTIES AND HARDNESS

TABLE 9.51

Source	Ref. 9.9			
Alloy	Type 301			
Condition	Ann		60% CW	
Irradiation temp, F	200	-	-416	-
Irradiation exposure, n (m^{-2})	3.9×10^{9}	Control	2.0×10^{17}	Control
Test temp, F	RT		-423	
F_{tu}, ksi	113.2	98.7	284	391
F_{ty}, ksi	87.0	38.4	284	300
e, percent	50.0	56.0	8	13
RA, percent	81.0	83.0	-	-
Hardness, R_B	94	94	-	-

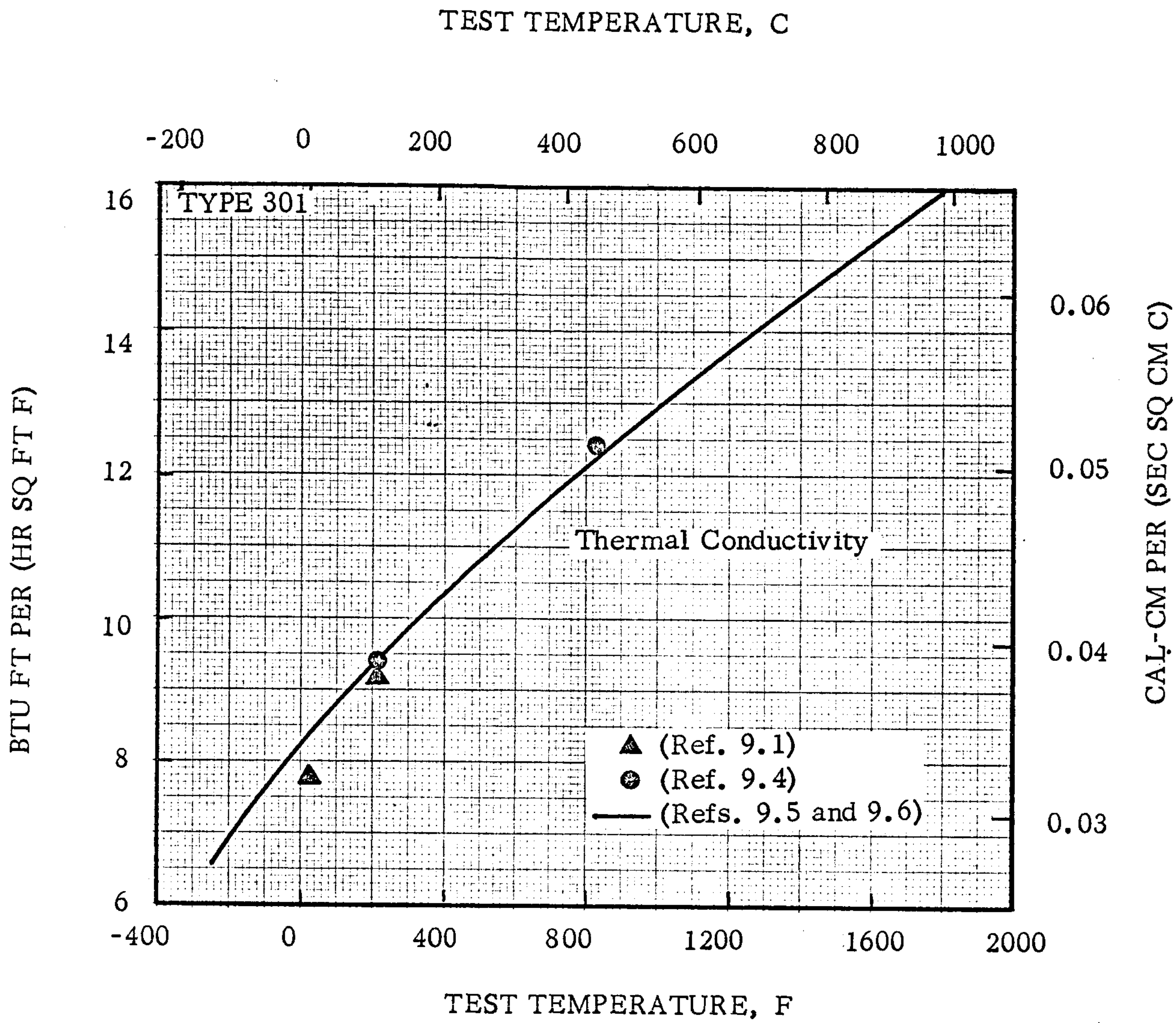

FIG. 9.21 THERMAL CONDUCTIVITY

(Refs. 9.1, 9.4, 9.5, 9.6)

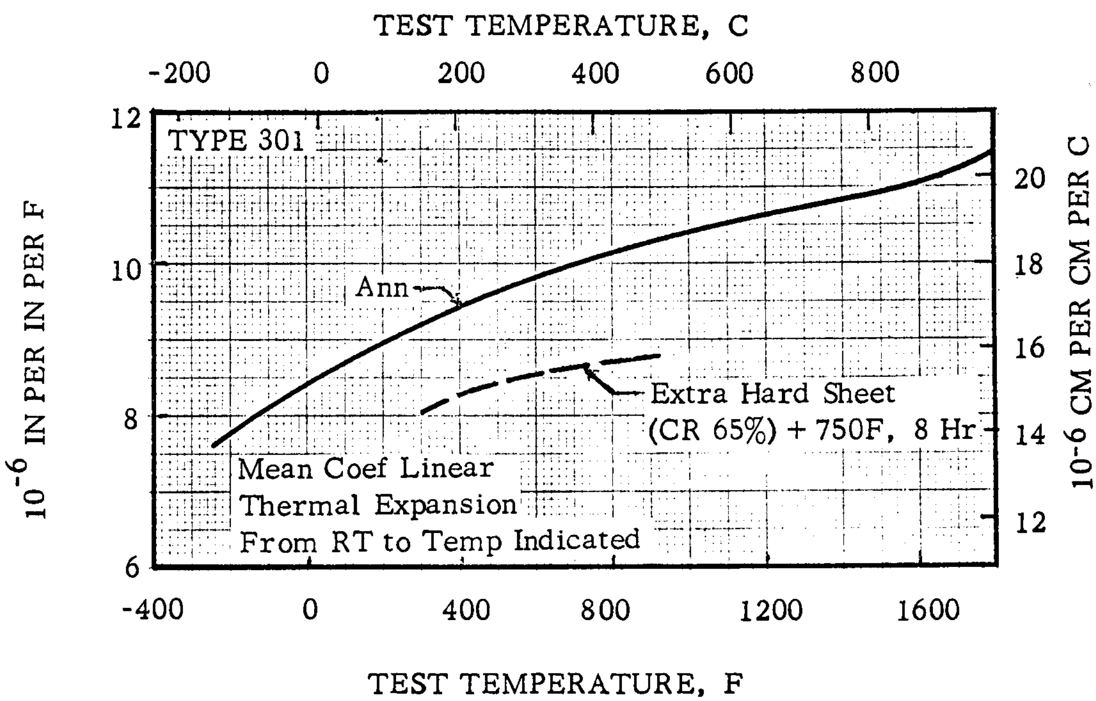

FIG. 9.22 THERMAL EXPANSION

(Ref. 9.5)

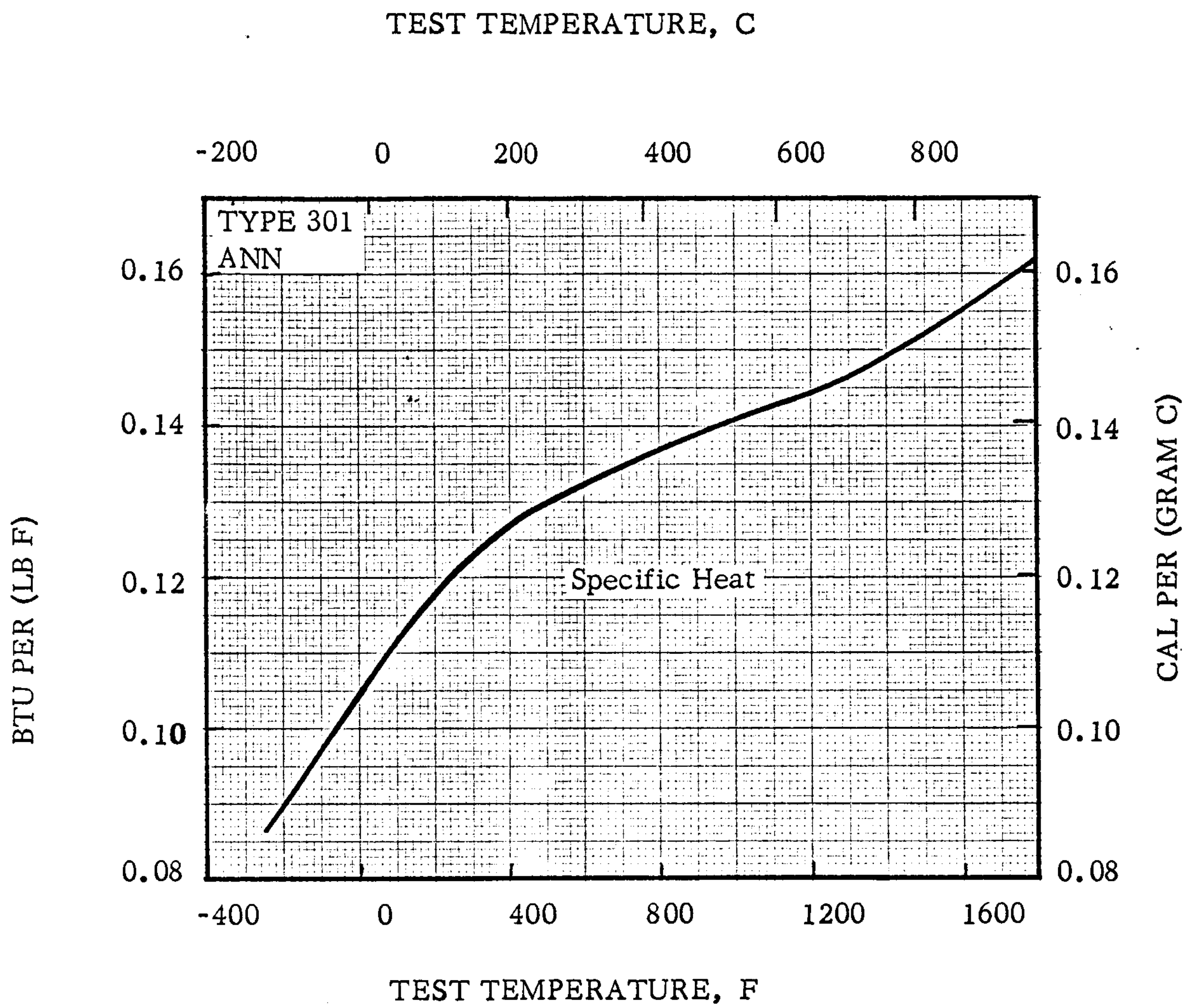

FIG. 9.23 SPECIFIC HEAT

(Ref. 9.5)

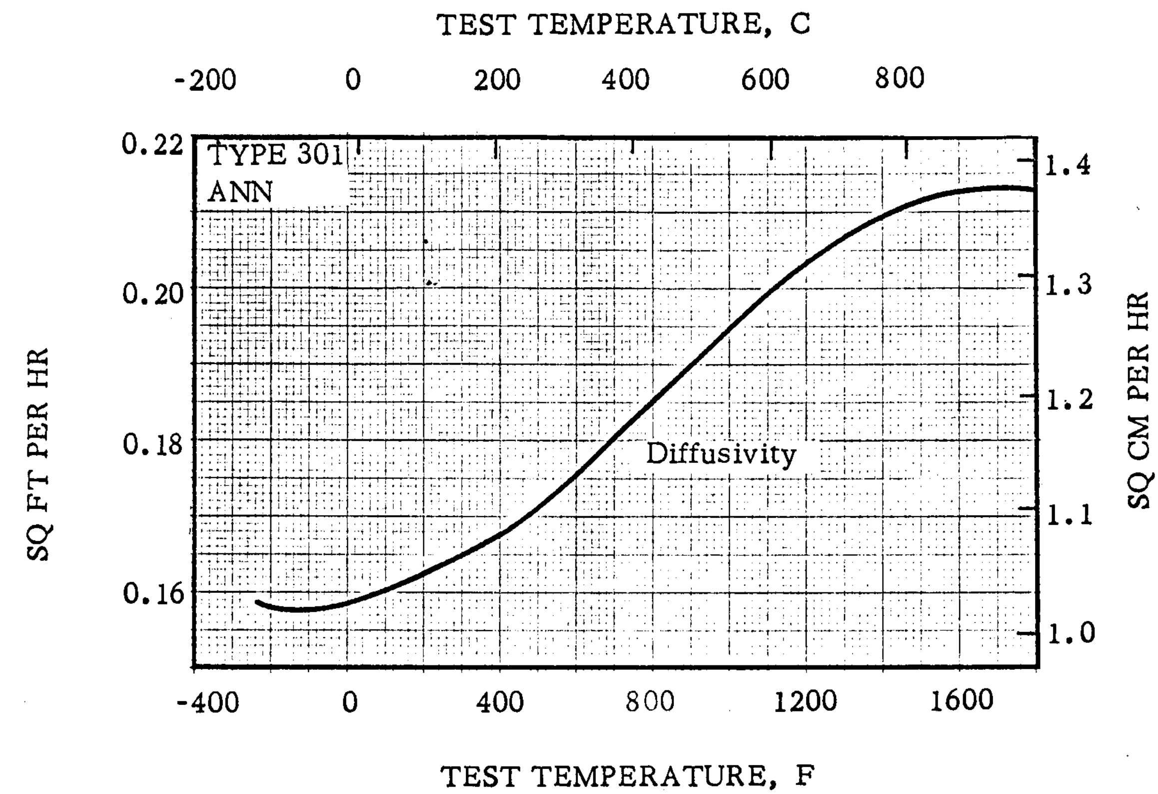

FIG. 9.24 DIFFUSIVITY

(Ref. 9.5)

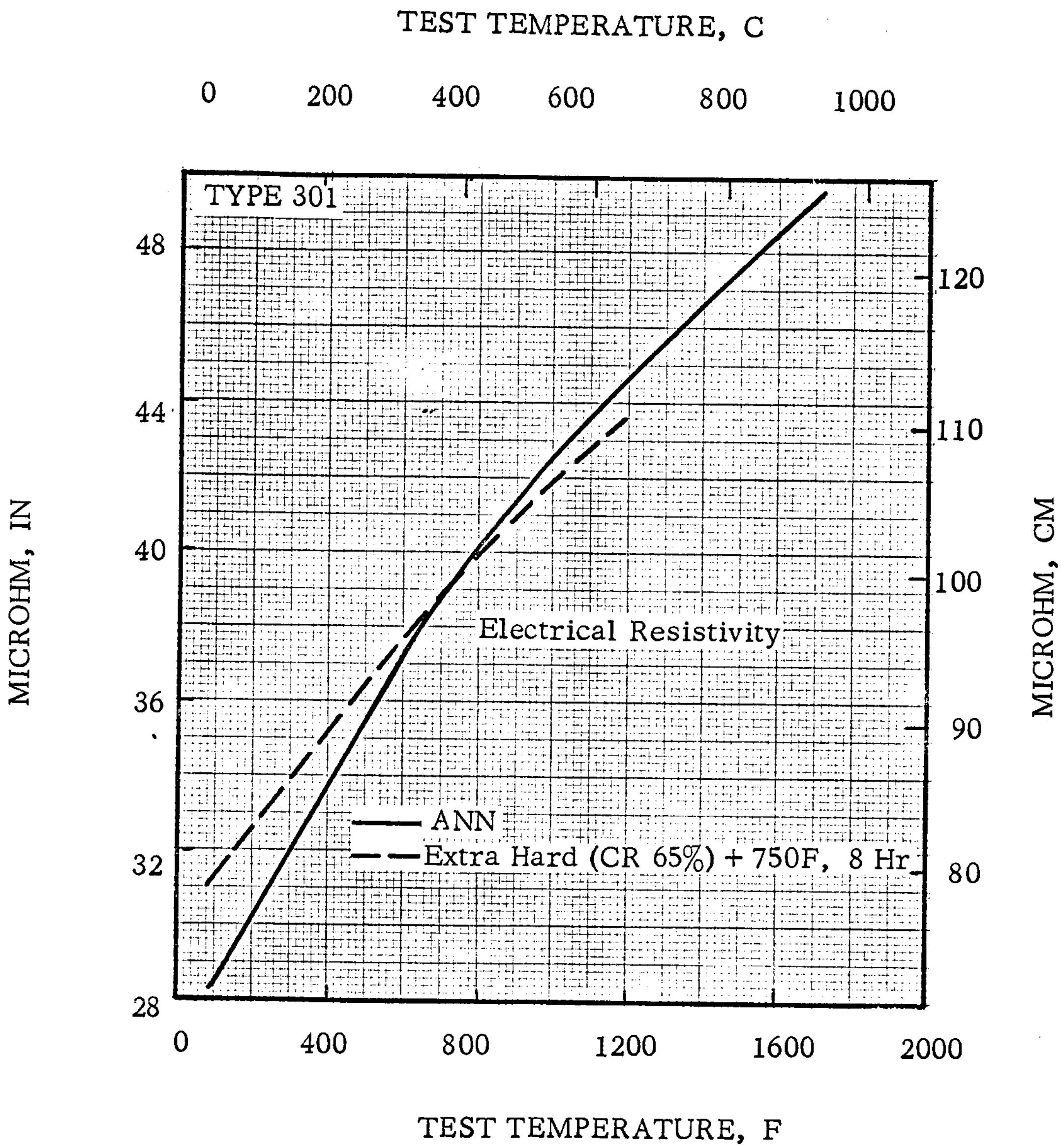

FIG. 9.31 ELECTRICAL RESISTIVITY

(Refs. 9.7, 9.8)

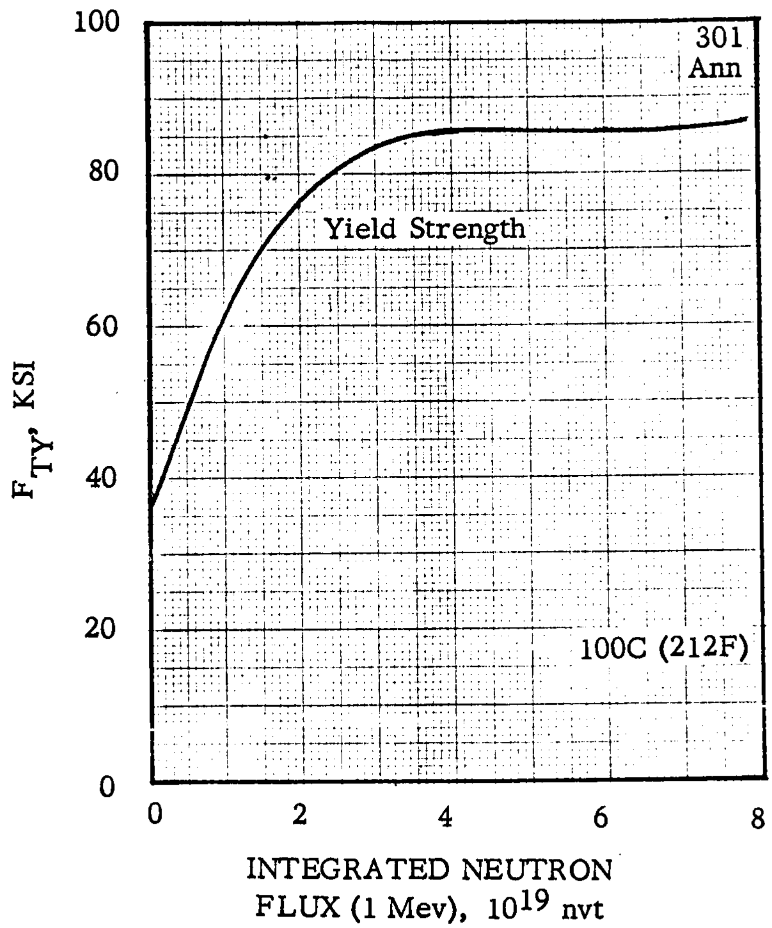

FIG. 9.52 EFFECT OF IRRADIATION BELOW 100C (212F) ON YIELD STRENGTH OF 301

(Ref. 9.11)

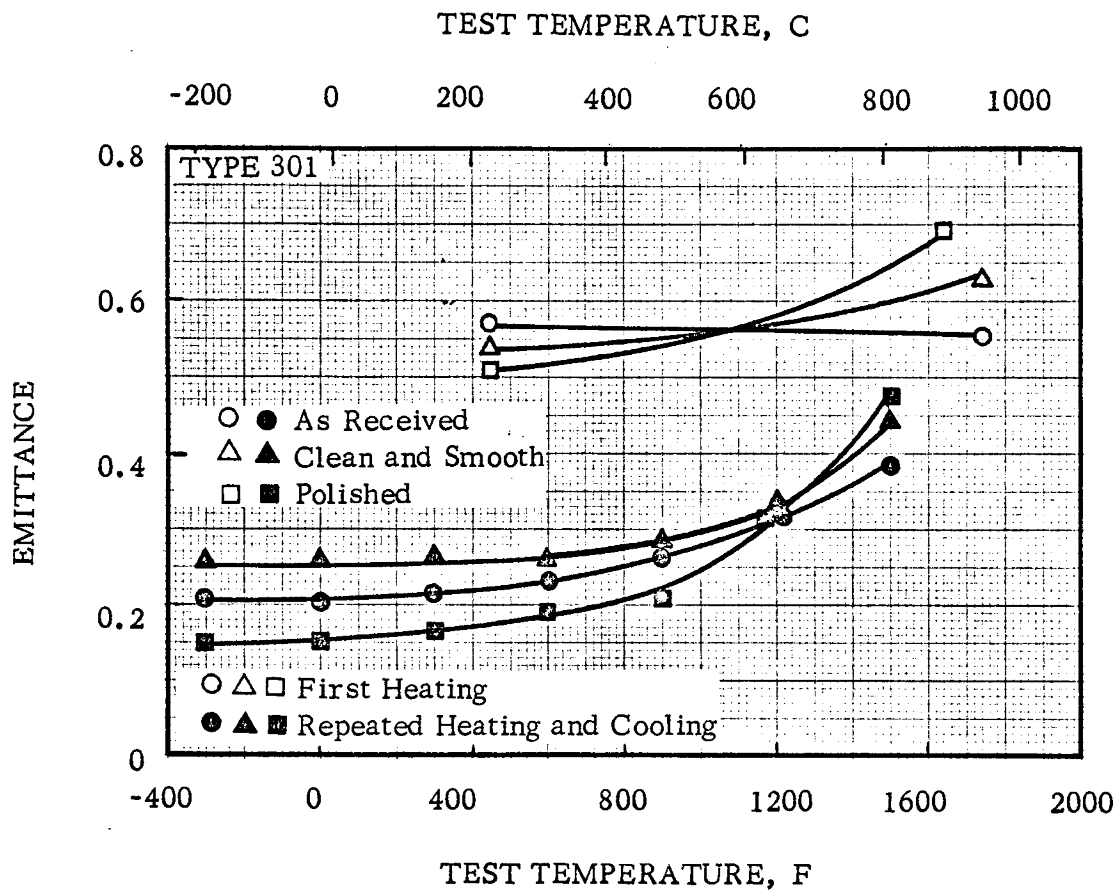

FIG. 9.61 EMISSIVITY

(Ref. 9.10)

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CHAPTER 10

CORROSION RESISTANCE AND PROTECTION

10.1 General. While the primary characteristic of Type 301 that is essential in its application to the missile and aircraft industries is that it may be work hardened to very high strengths, this material also exhibits excellent corrosion resistance properties. However, of all the steels in the 18-8 family of stainless steel, Type 301 is the least corrosive resistant. Type 302, whose chemistry is very close to Type 301 (except for the slight increase of chromium and nickel), exhibits slightly better corrosion resistance. Information will be given for Type 302 in this chapter where the same information is not known or available for Type 301. It must be remembered that the corrosion properties of Type 301 are similar, but the corrosion resistance is slightly less than that of Type 302.

The corrosion resistance of austenitic stainless steel is due primarily to its passivity. The passivity is dependent on the air formed oxide film on the surface of the metal. The oxide film is mostly chromic oxide which is increased in content by polishing. Films from highly polished specimens have been found to contain as much as 90 percent Cr_2O_3, (Ref. 10.1).

An oxide film will form on most metals that are exposed to air. This film will be so thin that it is invisible unless it is thickened by heating or chemical treatment. These oxides, which are insoluble in a corroding agent, are difficult to reduce electrochemically. They adhere well to the metal, do not crack or form pores and are effective barriers against corrosion. No oxide film is actually free from cracks or pores arising from stresses which occur in the film, but important to the oxides that create corrosion resistance is that any metal exposed would be automatically sealed with fresh oxide, (Ref. 10.2).

Chromic oxide is just such a film for stainless steel. In an oxidizing environment the film is strengthened, self generating and stable. A reducing environment tends to break down the film and cause the steel to corrode, (Ref. 10.3). The addition of 11.5 percent or more of chromium produces high passivity in stainless steel. The passivity not only depends on the amount of chromium, but to a great extent on the amount and condition of the carbon and its relation to the amount of chromium, (Ref. 10.4).

10.2 Atmospheric Corrosion. Austenitic stainless steels are highly resistant to atmospheric corrosion. Tests of 18-8 stainless steel exposed in the industrial atmosphere of New York City for 15 years showed a weight loss of 1.4 and 1.9 mg per square inch. Its appearance is described as very slight discoloration, mostly dirt, (Ref. 10.5). Atmospheric corrosion resistance can be improved by periodic cleaning of any dirt deposits that form. The dirt deposits prevent oxygen from getting to the metal surface and also brings corrosive matter, particularly chlorides, into contact with the metal, (Ref. 10.1). Tests were performed over a period of three years in a marine atmosphere. In the first months a thin superficial but adherent rust appeared and uniformly covered the surface and then became thicker with prolonged exposure. This rust was in greater quantity on the bottom side of the test sheets. After three years the rust was relatively thin on those panels that were initially polished and this rust could be removed with an appropriate metal cleaner. Panels that were cleaned every 6 months showed a lower rate of rust formation, (Ref. 10.6). Type 301 sheet tensile specimens in various conditions were exposed to the atmosphere at Niagara Falls, New York, for five years. After cleaning off an appreciable quantity of deposited dirt, an examination showed a mild pitting in some cases but not enough to mar the surface appearance. The exposure indicated no effect on the strength and ductility of the specimens, (Ref. 10.7).

10.3 Corrosion in Water. The 18-8 stainless steels remain practically unattacked by distilled water. Exposure to long periods of time in tap water, kept at about 140F at seven locations, has shown this steel to be highly resistant to corrosion. Some river waters, particularly those rivers near highly industrial cities, can be quite corrosive to many metals. 18-8 stainless steel shows almost complete corrosion resistance to river waters as indicated in Table 10.1.

Stainless steel behavior in marine waters will depend upon the conditions of exposure. If the velocity is low, marine organisms or other solid materials will become attached to the metal and will screen the oxygen and concentrate corrodants on the metal. Where the water velocity is high and matter cannot attach itself to the metal, corrosion is negligible, (Ref. 10.8). Galvanic corrosion may occur in sea water if a material more electropositive than Type 301 is in contact with the metal, (See Section 10.5 Galvanic Corrosion).

10.4 Intergranular Corrosion. When austenitic stainless steel is heated for a length of time between 800F and 1650F, chromium carbides will precipitate at the grain boundaries. This will reduce the chromium content of the adjacent material and reduce its resistance to corrosion. Corrosion then may occur along the grain boundaries. Welding operations may leave the area adjacent to the welds in this sensitive condition, which is then vulnerable to attack by corrosive media that would not ordinarily affect the steel. Common methods for eliminating this chromium carbide precipitation in Type 301 are (a) Use a very low carbon content and (b) anneal after any carbide precipitation has occurred, (Ref. 10.8).

10.5 Galvanic Corrosion. Galvanic action may take place if two dissimilar metals are in contact in the presence of an electrolyte. The metal that is more electropositive will dissolve or corrode, while the other material will not be affected. The metal more electropositive will become the anode, and the metal less electropositive will become the cathode in a galvanic cell. Ordinarily, stainless steel will act as the cathode with most materials and not be affected by galvanic action. Under some special conditions stainless steel may become activated; the current will reverse and the stainless steel will be attacked. Stainless steel may be activated by passing an electric current in a manner to make it anodic. This may be done intentionally when electrolytic etching or pickling is performed or unintentionally by accident or stray currents. If corrosion occurs, because stray currents are rendering the stainless steel active, this can be stopped by grounding or shunting the current or by proper insulation or by providing a counter current to neutralize the effect of the stray electric current, (Ref. 10.4). Table 10.2 shows the position of Type 301 in the galvanic series when active or passive.

10.6 Chemical Corrodents. Corrosion in the form of pitting usually occurs during continuous exposures to relatively weak corroding media, where the steel would be resistant otherwise. Pitting occurs in certain vulnerable spots where the passivity is continuously destroyed. Compounds or their acid radicals that are capable of causing pitting are some fluorides, chlorides, bromides, iodides, sulphides, sulphites, thiocyanates, and chlorites or hypochlorites. Pitting action will accelerate if in an acid condition. Corrosive solutions should not be permitted to stand for long periods of time in stainless steel equipment, particularly if the solutions are acidic. Making the solution alkaline will retard corrosion. Periodic cleaning and aerating of equipment is recommended as a procedure for retarding corrosion of equipment subject to chemical corrodents. An increase in temperature, pressure and concentration will increase the rate of corrosion. Alternate wetting and drying of the steel with a corrodent solution will create a concentration of the corrodent on the surface of the metal that may enhance the rate of corrosion. Similarly a partial immersion of the steel in a corrodent will create concentration of the corrodent because of evaporation at the surface of the solution, thus resulting in a more rapid rate of corrosion, (Ref. 10.4)

The 18-8 types of austenitic steels have excellent resistance to most types of atmospheric corrosion and are highly resistant to organic acids such as acetic acid and oxidizing acids such as nitric acid. However, they are not generally resistant to mineral acids such as sulphuric acid or to the halogen acids such as hydrochloric. A detailed Table of the corrosion resistance of the alloy to various chemical media, as determined in the laboratory, is given in Ref. 10.4 and is abstracted in Table 10.3. This should be taken only as a guide to the service life of the steel. Many service conditions cannot be duplicated in the laboratory such as impurities or combinations of chemicals. Also, cold working, stress, fabrication and surface finish all may have effects on the corrosion resistance.

10.7 Stress Corrosion. Residual stresses will be left in any metal after cold forming. The stressed metal may be slightly anodic compared to adjacent unstressed metal and, when subject to a corrosive media, stress corrosion may take place. The characteristic failure that takes place as a result of the stress corrosion is a brittle failure. Chemical environments that are conducive to stress corrosion cracking are caustic and chloride solutions for stainless steel. Tensile stresses, either external or residual, must be present on the surface of the metal for stress corrosion to occur, (Ref. 10.9).

Stress cracking may be pronounced in Type 301 steel in the formed condition, if high residual stresses are present. The tendency for stress cracking depends primarily on the value of tensile strength developed. Severely formed parts, particularily in the harder tempers of Type 301, should be immediately annealed or stress relieved to prevent cracking. Stress corrosion cracking may occur in certain medias, primarily hot chlorides, if residual stresses are present. Under normal atmospheric conditions stress corrosion does not normally occur even in extra hard sheet, (Ref. 10.10).

Results of tests on stress corrosion cracking under a variety of applied stresses and conditions show that, in general, Type 301 steel is very resistant to stress corrosion cracking in the environments tested. These stress corrosion tests were performed on both longitudinal and transverse sheet specimens of full hard, full hard and stress relieved and extra hard and stress relieved conditions. The specimens were subjected to an applied stress of 10-70 percent of their tensile strength and under a series of test environments. The natural environments were exposure at 80 feet and 800 feet from the ocean at Kure Beach, North Carolina and laboratory environments of 20 percent neutral salt spray and 3 1/2 percent NaCl solution; 10 minutes immersion and 50 minutes air dry cycle. Except for three specimens, all others were exposed about a year and more without any evidence of stress corrosion cracking, (Ref. 10.11).

Basic and fundamental information on corrosion and corrosion protection of metals for guidance in the design of military components is presented in Ref. 10.12.

CORROSION IN RIVER WATERS

TABLE 10.1

Source	Ref. 10.8		
Alloy	Type 301		
River	Duration of test, days	Corrosion rate, inches penetration per year	Pitting
Allegheny	330	0.000001	None
Monongahela	338	0.000002	None
Monongahela*	128	0.000005	None
Potomac*	394	0.000000	None
Mississippi	1095	0.000000	None

* Hot condenser water

TABLE 10.2

POSITION OF STAINLESS STEEL IN THE GALVANIC SERIES

★ ★ ★

ANODIC END

(Electropositive)

Magnesium	
Magnesium alloys	
Zinc	
Aluminum 2S	
Cadmium	
Aluminum 17ST	
Iron and carbon steel	
Copper steel	
4-6% Cr steel	
Stainless Type 410	
Stainless Type 430	
Stainless Type 446	
Stainless Type 301	Active
Stainless Type 302	
Stainless Type 309	
Stainless Type 310	
Stainless Type 316	
Lead-tin solder	
Lead	
Tin	
Nickel (active)	
Inconel (active)	
Brasses	
Copper	
Bronzes	
Copper-nickel alloys	
Monel	
Silver solder	
Nickel (passive)	
Inconel (passive)	
Stainless Type 410	
Stainless Type 430	
Stainless Type 446	
Stainless Type 301	Passive
Stainless Type 302	
Stainless Type 309	
Stainless Type 310	
Stainless Type 316	
Silver	
Graphite	
Gold	
Platinum	

CATHODIC END

(Electronegative)

NOTE: Metals toward the top of this series are electropositive to those toward the bottom and tend to corrode when in galvanic contact. The effect of passivation in moving the stainless steels toward the electronegative end of this series is also illustrated.

(Ref. 10.4)

TABLE 10.3

I FULLY RESISTANT	IV SLIGHTLY RESISTANT
II SATISFACTORILY RESISTANT	V NOT RESISTANT
III FAIRLY RESISTANT	

Substance	Temp, F	Type 302
Acetic Acid		
5% Agitated	70	I
5% Aerated	70	I
5%	100	I
5%	180	I
10% Agitated	70	I
10% Aerated	70	I
10%	100	I
10%	180	I
10%	Boiling	III
10%	60	I
15%	100	I
15%	180	I
15%	Boiling	III
20% Agitated	70	I
20% Aerated	70	I
20% Aerated	180	I
33%	70	I
33%	100	I
33%	180	I
33%	Boiling	III
40% Aerated	180	I
50%	70	I
50%	Boiling	III
60%	60	I
60%	100	I
60%	180	I
60%	Boiling	III
80%	70	I
80%	100	I
80%	180	I
80%	Boiling	IV
90% Aerated	180	III
100%	70	I
100%	100	I
100%	180	I
100%	Boiling	III
100% 150-lb. Press	400	V

Substance	Temp, F	Type 302
Aluminum Chloride		
10% Quiescent	70	IV
25% Quiescent	70	IV
Aluminum Potassium Sulphate (Alum)		
2%	70	I*
10%	70	I*
10%	Boiling	II*
Saturated	Boiling	III*
Ammonia (Dry or Moist)		
All concentrations	70-212	I
Ammonia (Anhydrous)	800 up	V
Ammonium Potassium Sulphate (Alum)		
Dilute and Saturated	Various	I*
Ammonium Sulphate		
1% Aerated	70	I
1% Agitated	70	I
5% Aerated	70	I
5% Agitated	70	I
10%	Boiling	II*
Saturated	Boiling	II
Benzene (Benzol)	70	I
	Hot	I
Bromine		
Bromine Water	70	V
Calcium Hypochlorite		
2%	70	II**
Aqueous Solution		
Sp.G. 1.04	100	III**
Carbolic Acid (Phenol)		
C.P. plus 10% water	Boiling	I
C.P.	70	I
C.P. (Boil)	360	I
Crude	212	I
Crude	Boiling	I

TABLE 10.3 (Con't)

Substance	Temp, F	Type 302
Carbon Tetrachloride		
C.P.	70	I
C.P.	Boiling	I
Chlorine Gas		
Dry	70	I
Moist	70	IV
	212	V
Chlorinated Water		
Saturated	70	III**
Chromic Acid		
5% C.P.	70	I
10% C.P.	70	II
10% C.P.	Boiling	III
50% C.P.	70	II
50% C.P.	Boiling	III
Commercial 50%		
(Cont. SO_2)	70	I
Commercial 50%		
(Cont. SO_2)	Boiling	IV*
Ferric Chloride		
1% to Saturation	70	V
Hydrochloric Acid		
All concentrations	70	V
Hydrofluoric Acid		
All concentrations	Cold & Hot	V
Nitric Acid		
5%	70	I
5%	Boiling	I
20%	70	I
20%	Boiling	I
40%	70	I
40%	Boiling	I
50%	70	I
50%	Boiling	I
65%	70	I
65%	Boiling	II
Conc.	70	I
Conc.	Boiling	II

Substance	Temp, F	Type 302
Fuming Conc.	70	I
Fuming Conc.	110	I
Fuming Conc.	Boiling	IV
Oxalic Acid		
5%	70	I
5%	Boiling	I
10%	70	I
10%	Boiling	IV
25%	Boiling	IV
50%	Boiling	IV
Phosphoric Acid		
1%	70	I***
1%	Boiling	I
1%-45-lb Press	284	I
5% Quiescent	70	I
5% Agitated	70	I
5% Aerated	70	I
10% Quiescent	70	I
10% Agitated	70	I
10% Aerated	70	I
10%	Boiling	I
25%	Boiling	I
45%	Boiling	II
50%	Boiling	II
80%	70	II
80%	230	V
85%	Boiling	V
Sodium Chloride		
5% Quiescent	70	I*
5% Quiescent	150	I*
20% Aerated	70	I*
Saturated	70	I*
Saturated	Boiling	II*
Sodium Hydroxide	70	I
20%	Boiling	I
30%	Boiling	II
Molten	600	II

TABLE 10.3 (Con't)

Source	Temp, F	Type 302
Sulphuric Acid		
5%	70	III
5%	Boiling	V
10%	70	III
10%	Boiling	V
50%	70	IV
50%	Boiling	V
Conc.	70	I
Conc.	Boiling	IV
Conc.	300	V
Fuming	70	III
Sulphurous Acid		
Saturated	70	III
Saturated 60-lb Press	250	III
Saturated 70-125-lb Press	310	III
Saturated 150-lb Press	375	III
Spray	70	IV*

* Subject to pitting at air line or when allowed to dry.

** Not recommended for standing baths.

*** May attack when hydrochloric acid is present.

(Ref. 10.4)

CHAPTER 10 - REFERENCES

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CHAPTER 11

SURFACE TREATMENT

11.1 General. The surface of Type 301 may be treated mechanically, chemically and electrochemically. The purpose of surface treatment for Type 301 is to:

1. Remove scale developed during heat treatment
2. Improve the corrosion resistance
3. Provide an attractive decorative finish

11.2 Scale Removal. The very high temperatures that are attained during welding, annealing and forging will develop sufficient scale to make its removal necessary. Such a scale will impare the metal's appearance and corrosion resistance. If Type 301 is to be fabricated such as by cold working or welding, it must be scale free. Scale left on a surface that is to be cold worked may lead to tearing and induced corrosion attack. Descaling may be carried out by various pickling solutions, sand blasting or electropolishing, (Ref. 11.1). Scale removing processes must be controlled with great care, otherwise the fabrication is hindered and impairment of anti-corrosion properties may ensue, (Ref. 11.2).

The scale or oxide formed on stainless steel under very high temperatures may be heavy and difficult to remove. In such cases it may be necessary to employ more than one pickling bath to remove the scale. An initial bath is used to soften the scale and a second bath will remove the scale. For more tenacious scales, an intermediate bath may be necessary to assist in the softening of the scale. Under a number of annealing conditions the scale may be light enough to be removed by a one bath process, (Ref. 11.3). The acids most commonly used in making up pickling solutions for de-scaling stainless steel are nitric, hydrofluoric, sulphuric and hydrochloric, (Ref. 11.5). Nitric acid is an oxidizing agent whereas the other acids are reducing. An oxidizer will promote and preserve the passivity of stainless steel while reducers will de-scale by reducing the oxide but also reduce the protective oxide film, (Ref. 11.5).

The reducing agents are used to soften the oxide scale and are followed by a nitric acid bath to remove the softened scale and preserve the passivity. When nitric acid is used alone it will not act to dissolve and remove oxide scale from stainless steel; thus for single bath pickling hydrofluoric acid is usually added to nitric acid.

A recommended two bath pickling process utilizes the following solutions:

Solution A

15 to 20 percent sulfuric acid (Sp. Gr. 1.84) by volume
Balance water, maintain at 140 to 150F.

Solution B

15 to 20 percent nitric acid (Sp. Gr. 1.42) by volume
Balance water, maintain at 150F.

Immerse in Solution A for not more than five minutes or until scale is loose, rinse in water, then follow with a five minute immersion in Solution B, rinse in water and dry. If this pickling process is the last step and a bright finish is desired, 1 to 3 percent by volume hydrofluoric acid can be added to Solution B, (Ref. 11.3).

Where small parts, that are handled manually, are produced and the anneal produces a brittle dark scale, which is the least difficult to remove of all scales, then it is possible to remove it by a single bath. Solution B, with the hydrofluoric acid, is used in this case. The parts should then be flushed in water and possibly brushed with soft brushes to remove scale, (Refs. 11.3 and 11.5).

Additional pickling solutions may be used:

Solution C

10 to 14 percent sodium hydroxide, by weight
3 to 6 percent potassium permanganate, by weight
Balance water, maintain at or near boiling.

This solution may be used as an intermediate bath between Solution A and B, where the scale is very difficult to remove. The usual immersion time is 20 to 30 minutes, (Ref. 11.3).

Solution D

5 to 10 percent sulfuric acid (Sp. Gr. 1.84) by volume,
2 to 4 percent hydrochloric acid (Sp. Gr. 1.19) by volume,
Balance water, maintain at 160F, (Ref. 11.3).

This solution may be substituted for Solution A. Very close control must be maintained with the use of this solution, because when exhausted it tends to cause pitting and become very corrosive, (Ref. 11.3). Solutions containing sulfuric and/or hydrochloric acids tend to cause pitting. There are several commercially available inhibitors that will minimize this effect. Nitric acid when used above 150F will fume badly, which is dangerous to those working with it and it rapidly exhausts the strength of the bath. Commercially available foaming agents will minimize this effect, (Ref. 11.3).

Molten baths of caustic or alkali are used to change the composition of the scale and make its removal relatively easy on the subsequent acid bath, (Ref. 11.3).

One type of bath uses molten sodium hydroxide to which about 2 percent sodium hydride has been added. This bath is maintained at 750F or higher. This will reduce the oxide of the scale. The steel is then removed from the bath and water quenched. The steam generated usually blasts off most of the scale. The steel is then immersed in an acid bath of almost 10 percent sulfuric acid, where the balance of the scale is removed. After a water rinse, a solution similar to Solution B is used to brighten the finish, (Ref. 11.3).

11.21 Sandblasting is a common and well known method to remove the scale from ordinary carbon steels. It is, however, not in common practice for stainless steel. If used the sand should be clean and free from iron and if hardened steel grit is used, the metal surface should be acid cleaned to remove all traces of free iron. Pickling follows to make sure that the scale is completely removed. Electrolytic polishing processes have been developed that provide a fine high finish on parts after fabrication and assembly. In electropolishing the stainless steel is made the anode and metal is removed into solution, (Ref. 11.2).

11.3 Passivation. The final surface treatment usually recommended for stainless steel, before it is ready to be put in service, is passivation. The passivation treatment will produce a stronger and better oxide film that will resist corrosion. In the drawing, forming, machining and other fabrication of stainless steels, the steel must come in contact with other steels and may pick up on their surface small amounts of free iron or "tramp iron". If this free iron is allowed to remain on the surface it will soon rust, marking the stainless steel surface and more significant, it leads to localized pitting and eventual corrosion.

Nitric acid is the recommended solution for passivation. 30 percent nitric acid by volume heated to 120 to 140F for 15 to 30 minutes is a recommended procedure for passivation of Type 301 and this should be followed by a water rinse, (Ref. 11.3).

11.4 Standard Finishes. For flat rolled stock, the mill finishes are divided into two categories; unpolished and polished finishes. Table 11.1 shows the finishes available for flat rolled material, and Table 11.2 the available finishes for bar and wire.

The bright and dull finishes for mill rolled sheet are produced by applying a light cold rolled pass on either polished or dull rolls. The various polished finishes are accomplished with abrasives and buffing processes to produce the finish desired.

11.5 Protection of Finish. Stainless steel should be properly protected during the various fabrication processes to avoid unnecessary scratches and contaminations. Not only do such scratches and contaminations score the surface of the stainless steel, but form a nucleus for pitting and corrosion. Protection of the material can be made by the use of plastic coatings or adhesive paper which can be peeled off later. Ample lubrication should be used during drawing operations, and paper under hold down pads and adhesive paper on the edges of brakes will avoid excessive marking and scoring.

Areas adjacent to welds may turn brown under some alternating wet and dry conditions. This is an oxide film that should be removed. Stainless steels are tougher than ordinary carbon steels and they tend to drag and wear out wheels more rapidly in the grinding, polishing and buffing process. Since they conduct heat away more slowly, they will overheat and warp more easily. It is therefore, recommended, to use a lubricant on all finish grinding operations. All wheels, buffs, dies, etc. should be checked constantly to see that they are not contaminated with other metals. These metals, when imbedded in the surface of the stainless steel, may cause galvanic corrosion under moist conditions. Buffing and greasing components should be free of iron or iron-oxide.

FINISHES AVAILABLE IN FLAT ROLLED

TABLE 11.1

Source	(Ref. 11.4)
Alloy	Type 301
Mill Rolled Finishes	
Cold rolled strip No. 1 finish - cold rolled annealed and pickled No. 2 finish - bright cold rolled No. 2 finish - bright annealed Sheets No. 1 finish - hot rolled, annealed and pickled No. 2B finish - bright cold rolled No. 2D finish - dull cold rolled Hot Rolled Plates Hot rolled Hot rolled and annealed Hot rolled, annealed and pickled	
Mill Polished Finishes (on one or both sides)	
Sheets and Plates No. 3 finish - intermediate polish No. 4 finish - standard polish No. 6 finish - Tampico brushed polish No. 7 finish - high luster polish No. 8 finish - mirror polish	

FINISHES AVAILABLE IN BAR AND WIRE

TABLE 11.2

Source	(Ref. 11.4)
Alloy	Type 301
	Hot Rolled Bar
Hot rolled Hot rolled and annealed Hot rolled, annealed and pickled Hot rolled and rough turned Hot rolled, annealed and rough turned	
	Hot Rolled Wire
Hot rolled Hot rolled and annealed Hot rolled, annealed and pickled	
	Cold Finished Bar
Annealed and cold drawn Heat treated and cold drawn Annealed and centerless ground Heat treated and centerless ground Annealed centerless ground and polished Heat treated, centerless ground and polished	
	Cold Finished Wire
Annealed and cold drawn Heat treated and cold drawn	

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CHAPTER 12

JOINING TECHNIQUES

12.1 General. Type 301 stainless steel is readily welded by all fusion and resistance welding methods. Both soft and hard soldering can also successfully be performed on this alloy. Copper brazing can be accomplished under controlled conditions. Stainless steel can be riveted but requires techniques different from the plain carbon steel methods. Welding techniques have been made sufficiently adaptable to stainless steel so that riveting is employed only in those applications where welding is not suitable because of structural requirements.

12.2 Welding. All methods of welding applicable to carbon steel, except hammer or forge welding, can be readily used for Type 301. Austenitic stainless steels are not normally preheated. Because of carbide precipitation (see Section 10.4) the areas adjacent to welds are more sensitive to corrosion than the parent material. The forming of chromium carbides at the grain boundary during welding does not affect the structural strength, but may lead to failure if subjected to severe corrosive conditions. When parts are left as-welded and subsequently exposed to severe corrosive conditions and when the parts are to be operated at 800F to 1650F, a stabilized type stainless steel such as Types 321 or 347 should be specified. When exposure is below 800F, the stabilized types are unnecessary and the low carbon stainless steel types such as 304L and 316L are normally satisfactory, (Ref. 12.14).

Where use requires the same corrosive resistance for the welded joint and the parent material, then the welded parts should be fully annealed and then rapidly quenched thereby dissolving the carbides. Because of the rapid heating and cooling possible with resistance welding, carbide precipitation along grain boundaries is minimal. Consequently, corrosion resistance is usually not adversely affected when the material thickness is less than 1/8 inch. When thickness is greater than 1/8 inch and the welded structure is to be subjected to a corrosive exposure, a low carbon or stabilized grade of stainless steel should be used, (Ref. 12.15). Greater care must be taken in cleaning the welded area of any carbonaceous materials that may be picked up in earlier stages of fabrication. The carbonaceous material raises the carbon content of the weld and will reduce its corrosion resistance. The coefficient of thermal expansion of austenitic stainless steel is about 60 percent greater than that of mild steel. Warpage or distortion at the weld will result if these thermal properties are not properly accounted for in the design of welded equipment and welding fixtures, (Refs. 12.1 and 12.3). The most effective means to prevent fissuring or cracking of the weld metal is to adjust the composition of the weld deposit to include small amounts of ferrite. This can be accomplished by proper selection of filler metal composition. Ordinarily 3 to 4 percent ferrite is adequate. If the welds are in heavy sections, 6 to 7 percent ferrite may be required. The amount of ferrite in a weld is basically a function of its chemical composition and can be predicted from the Schaeffler Diagram, (See Fig. 12.1). Cooling rate and subsequent heat treatment also influence the amount of ferrite in the weld, (Ref. 12.1).

The heat of welding will reduce the mechanical properties of strain hardened material to those of annealed Type 301. Planishing will improve the tensile strength of weld metal by cold working, but will have little effect on the mechanical properties of the heat-affected zone, (Ref. 12.4).

The strengthening of the weld joints may also be accomplished by using reinforcing plates or thickened joints, (Ref. 12.5).

12.21 Fusion Welding. For material less than 1/8 inch thick, fusion welding is ordinarily performed without filler metal. For heavier material, the filler metal alloying composition should be at least that of Type 301 or higher. For corrosion application, the carbon content should be restricted to low levels, about 0.03 to 0.04 percent or even lower. The most widely used methods of fusion welding are by electric arc procedures. Flame welding, such as with an oxy-acetylene torch, is not generally recommended. Where used (and only by sheer necessity), it is used for thin material and the flame adjustment should be strictly neutral in order to prevent carburization. It is difficult to make a satisfactory weld with an oxidizing flame, (Ref. 12.2).

Electron and laser beam welding are two relatively new non-arc procedures that have some application in the welding of stainless steel, (Refs. 12.5 and 12.6).

Metal arc welding with flux-coated filler rods is the most widely used process for welding heavier stock material. Either AC or DC current may be used, although DC is ordinarily preferred. A coating of AC-DC titania flux or DC lime-base flux may be used as a rod coating. For welds thicker than 1/4 inch, multiple beads should be used. The slag must be thoroughly cleaned from each proceeding weld bead, before starting the next weld. The recommended current ranges for AC or DC metal are shown in Table 12.1, (Ref. 12.2).

Austenitic stainless steels have physical properties that are different from those of carbon steels and their welding procedures are accordingly altered. The electrical resistance of austenitic stainless steel is about six times greater than carbon steel, the melting point about 200F lower and the thermal conductivity about 50 percent less. For these reasons the welding current requirements for stainless steel are lower than for carbon steels, (Ref. 12.16).

The submerged-arc process and atomic hydrogen welding are also used for stainless steel, (Ref. 12.7). Atomic hydrogen fusion welding has its chief use for thin sheets and strip from 0.010 inch to 0.140 inch, although it is also suitable for heavier gage work. It is adaptable to butt, lap, filler and raised edge-joints. The fusion and bonding take place under a constant protective shield of hydrogen, which because of its reducing action protects against oxidation from the surrounding atmosphere as well as burning away of the edges and holing through on light work. The welds exhibit a surface smoothness that reduces the amount of subsequent finishing, (Ref. 12.14). Submerged arc welding employs a continuous electrode which makes possible uninterrupted depositing of filler metal under protection of flux separately applied, (Ref. 12.14).

The most widely used process of producing welds of high quality are the two inert-gas arc welding processes, TIG and MIG. The TIG method is performed on this metal with a single non-consumable tungsten electrode with an opening in the welding torch for the inert gas, usually argon to be introduced around the arc. The MIG method is generally used for 1/8 inch thick steel or heavier and employs a filler metal as the electrode fed from a reel of wire through the welding gun into an inert gas atmosphere. The gas mixture used is 98 percent argon and 2 percent oxygen. These provide excellent quality welds at high speeds with no flux removal problems, (Ref. 12.2). The effects of low temperatures on TIG weld tensile properties of cold rolled sheet are shown in Figs. 12.2 and 12.3.

12.22 Resistance Welding. The high electrical resistance of austenitic stainless steels permits rapid heating, limited to a small area and allows electrical resistance welding to be an efficient, highly recommended joining procedure for this steel. Resistance welding is done under water or a stream of water directed at the weld or more commonly the electrodes are cooled with water circulating through its hollow portion. This cooling minimizes warpage and carbide precipitation, (Ref. 12.10). The primary requirements for resistance welding are; clean metal surface, sufficient pressure, correct joint and electrode design, sufficient power and accurate timing, (Ref. 12.2). Spot, seam or stitch welding, butt and flash resistance welding are ordinarily performed on Type 301. More recent applications of high-frequency resistance welding have also been made on this stainless steel.

Resistance welding is sometimes used in conjunction with fusion welding. A sheet welded together by the TIG process can be reinforced at the joint by a back up sheet joined by spot welds. Low cycle fatigue data for such a complex joint is given in Fig. 12.4. Efficiency of parent metal in tension for spot-welded sheet in the annealed, 1/4 hard, 1/2 hard and full hard conditions are given in Figs. 12.5, 12.6 and 12.7 for various sheet gages.

12.3 Brazing. Copper brazing requires protective atmospheres and high purity copper. Temperature of 2050-2100F are needed to melt and flow the copper, (Ref. 12.14). Corrosion due to galvanic action may occur if a brazed part is subjected to wet corrosive conditions. Silver-alloy brazing (also called "silver soldering" or "hard soldering") is discussed in the next section, (Ref. 12.3).

12.4 Soldering. Both soft and hard soldering may successfullly be performed on Type 301 stainless steel. 50 percent tin and 50 percent lead solder is most commonly used for soft soldering. Higher tin percentages up to 100 percent may be used to create better color match and a stronger joint. Roughening the steel surface helps the solder to adhere, for it is difficult to make solder adhere to a bright or highly polished stainless surface.

Fluxes especially prepared for stainless steel should be used. Improper fluxing is often the cause of joint failures. Fluxes should be neutralized immediately after the joint is made, then flushed away with water. Soft soldered joints cannot be depended upon for their mechanical strength and are used primarily as a seal. If strength is required in addition to a seal, the soldered joint should be used in conjunction with another joining device, such as spot welding, riveting or lock seaming, (Ref. 12.3).

A very satisfactory joint may be obtained by silver soldering. This method is often used to join stainless steel to copper, bronze, another steel, stainless steel, or many non-ferrous metals. A sound, strong, gas-tight and liquid tight joint is made if proper procedures are followed. Good silver-alloy joints have tensile strengths greater than 40,000 psi, (Ref. 12.3).

12.5 Riveting. Rivets are available in this grade of stainless steel and no trouble should be experienced in driving sizes 3/16 inches and smaller. Larger size rivets should be hot driven. The rivets should not be heated more than 10 minutes and to the temperature range of 2000 to 2200F. In no case should the rivets be driven at temperatures below 1800F, (Ref. 12.3).

12.6 Mechanical Joints. A number of lock joints and edge reinforcements may be used on stainless steel sheets not thicker than 0.062 inch. Some of these joints are designed to be filled with soft solder. The lock joint will provide mechanical strength while the solder will provide a seal, (Ref. 12.2).

CURRENT RANGES FOR AC-DC METAL ARC WELDING

TABLE 12.1

Source	(Ref. 12.2)					
Alloy	Type 301					
Electrode diameter (in)	Material Gauge U.S. Std.	Material Gauge Equiv inches	Volts	Flat amp.	Vert up amp.	Over head amp.
1/16	24-20	0.025-0.037	20	20- 35	20- 25	20- 30
5/64	22-16	0.030-0.062	21	30- 45	30- 33	30- 40
3/32	18-12	0.050-0.109	22	50- 70	45- 55	50- 60
1/8	12- 7	0.109-0.187	23	90-110	75- 85	90-100
5/32	7- 7-o's	0.087-0.500	24-25	125-150	95-110	125-140
3/16	3- o's	0.375-0.750	25-27	155-195	105-120	155-185
1/4	-	>0.375	26-28	240-290	-	-
5/16*	-	-	27-30	325-375	-	-

* AC current recommended
If DC used, employ procedures to avoid arc blow.

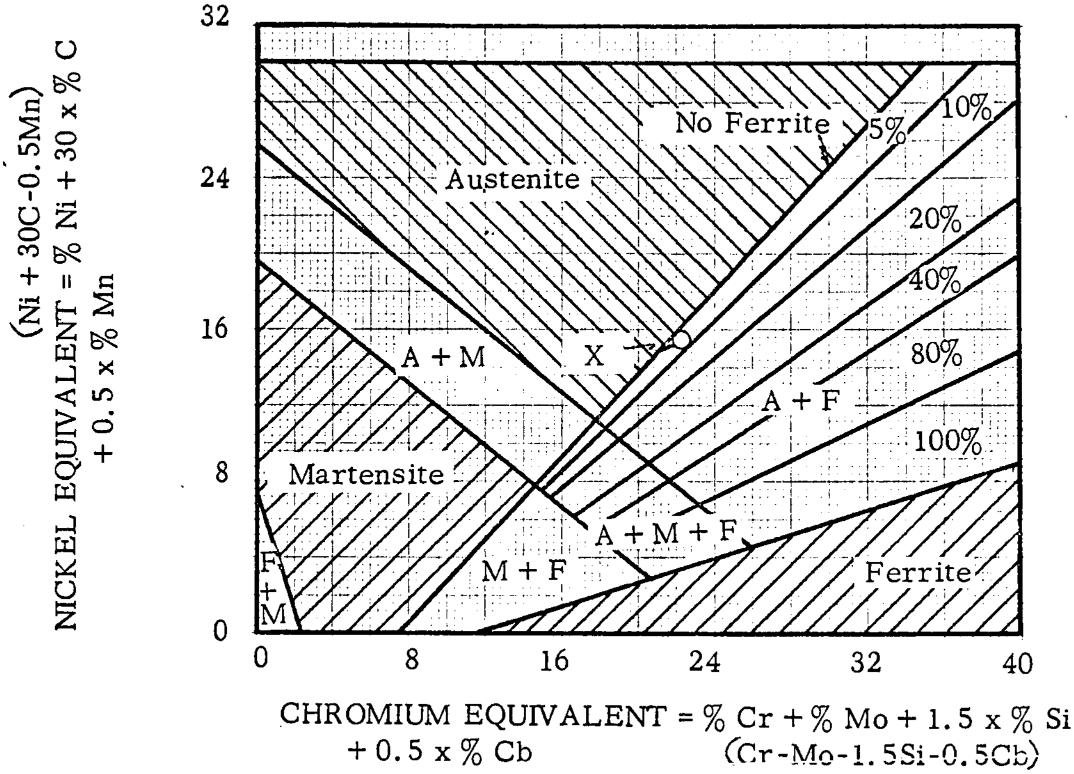


FIG. 12.1 SCHAEFFLER DIAGRAM - FERRITE AS DETERMINED FROM CHEMICAL COMPOSITION OF AUSTENTIC STAINLESS STEEL

(Ref. 12.8)

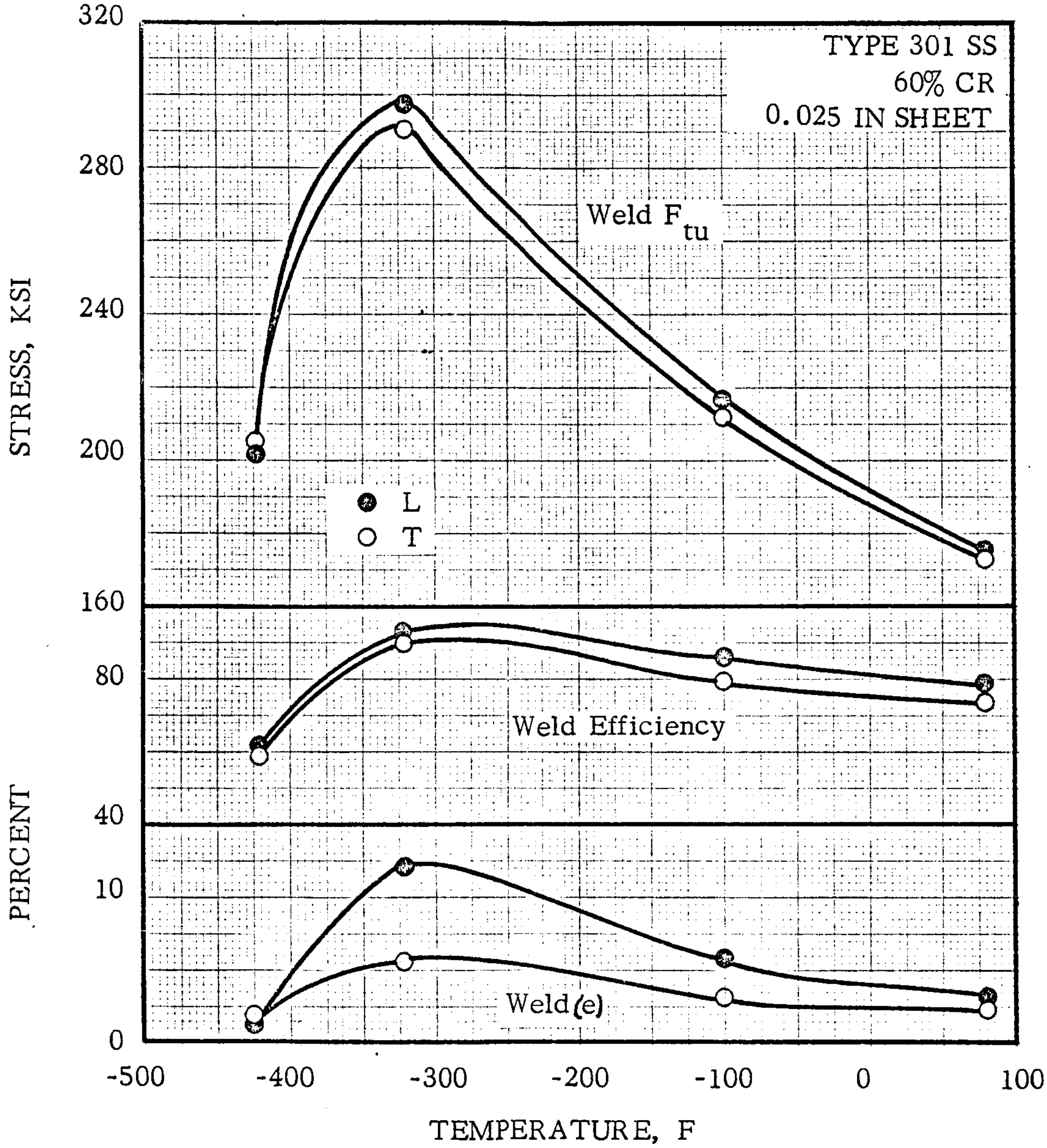


FIG. 12.2 EFFECT OF LOW TEMPERATURES ON TENSILE PROPERTIES AND EFFICIENCY OF TIG BUTT-WELDED SHEET

(Ref. 12.9)

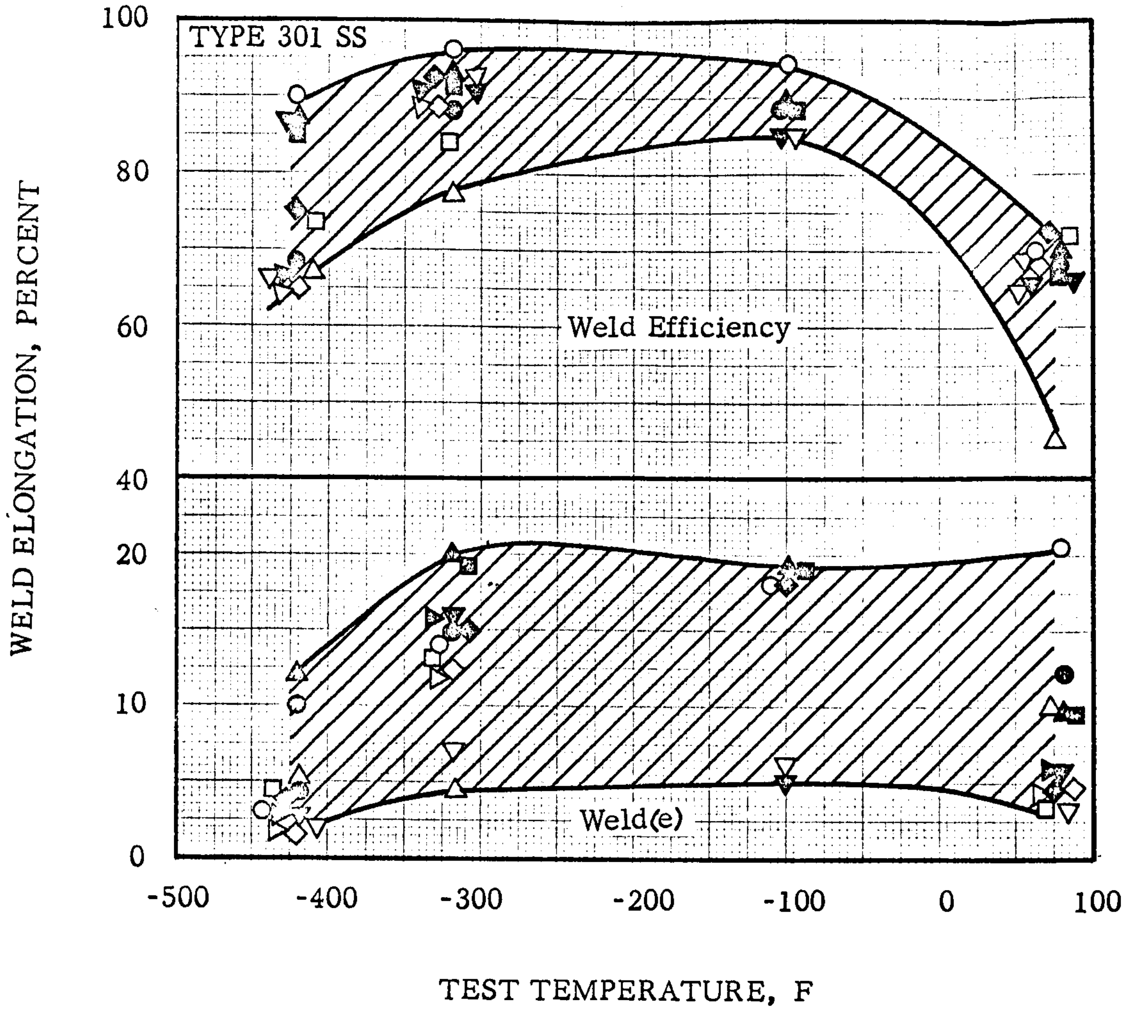


FIG. 12.3 EFFECT OF LOW TEMPERATURE ON EFFICIENCY OF TIG BUTT-WELDED SHEETS OF VARIOUS THICKNESS AND CONDITIONS (Ref. 12.17)

L	T	t	Condition	Weld
○		0.100	-	Roll Planished
△		0.080	60% CR	-
□		0.060	60% CR	Roll Planished
▼		0.032	XFH	Roll Planished
◇	◇	0.023	XFH	Roll Planished
△	△	0.020	62% CR	Roll Planished
○		0.016	42% CR	Roll Planished
△		0.015	78% CR	Roll Planished
□	▽	0.013	XFH	Roll Planished

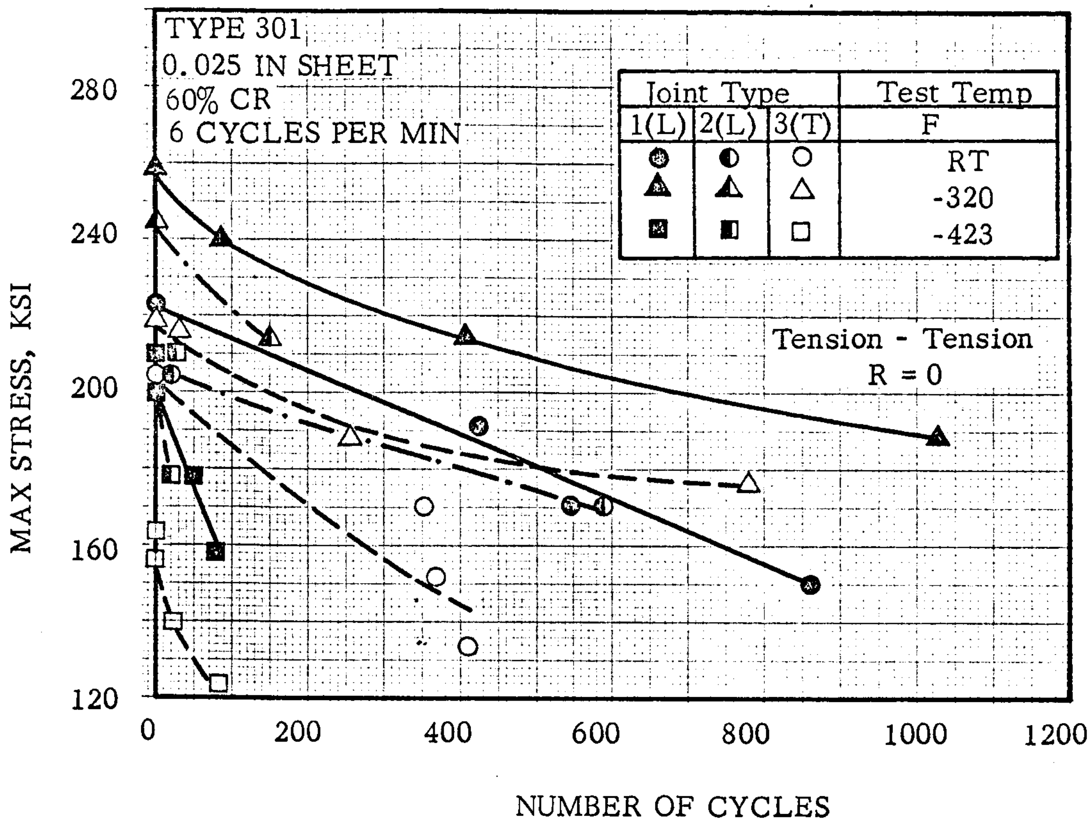
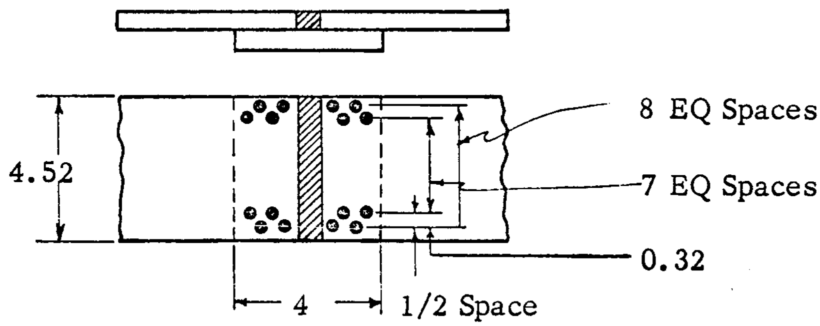
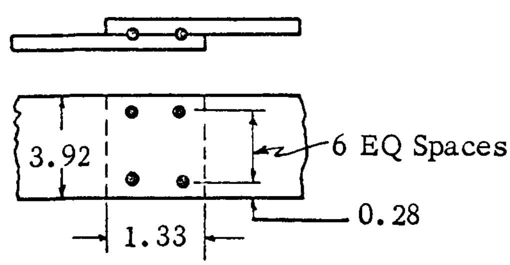


FIG. 12.4 LOW CYCLE S-N CURVE FOR COMPLEX WELDED JOINTS OF 60 PERCENT COLD ROLLED SHEET (Ref. 12.9)



Joint 1 (L): Heliarc buttweld plus spotweld doubler

Joint 2 (L): Same as 1 (L) except 2 rows of spotweld on each side of buttweld instead of 4.



Joint 3 (T): Resistance Spotweld

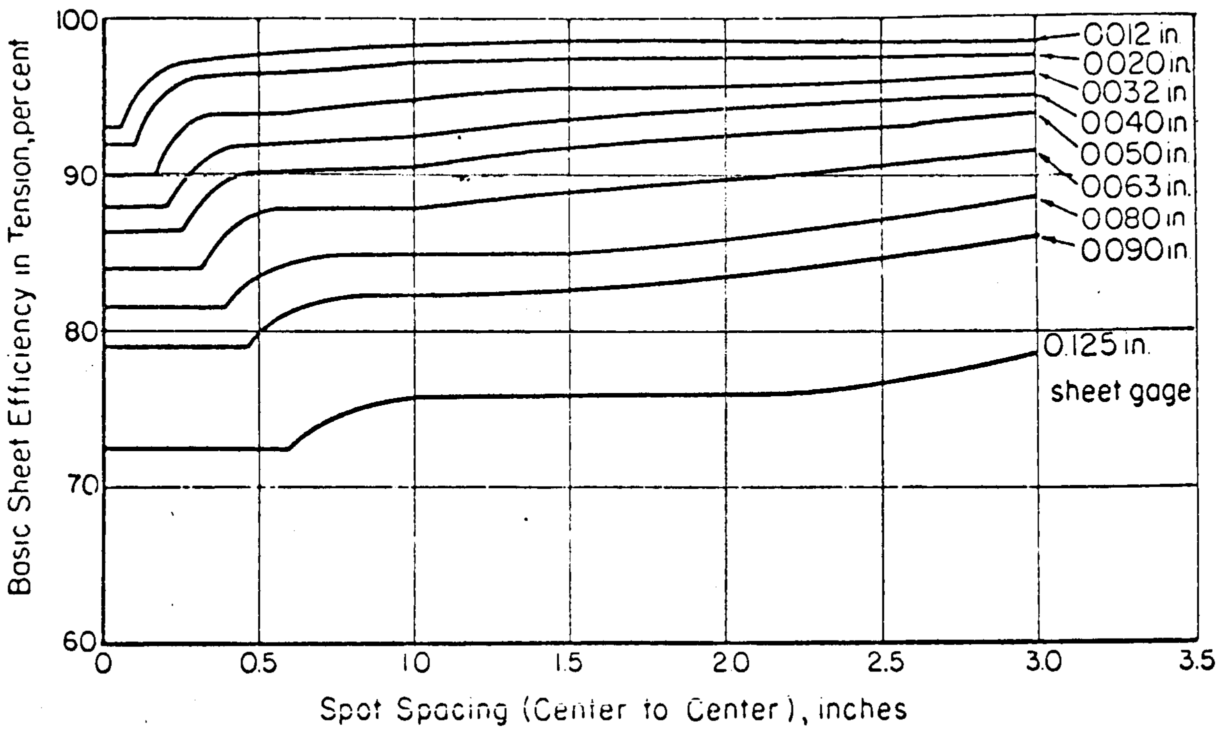


FIG. 12.5 EFFICIENCY OF THE PARENT METAL IN TENSION FOR SPOT-WELDED TYPE 301 SHEET IN ANNEALED AND 1/4 HARD CONDITION

(Ref. 12.13)

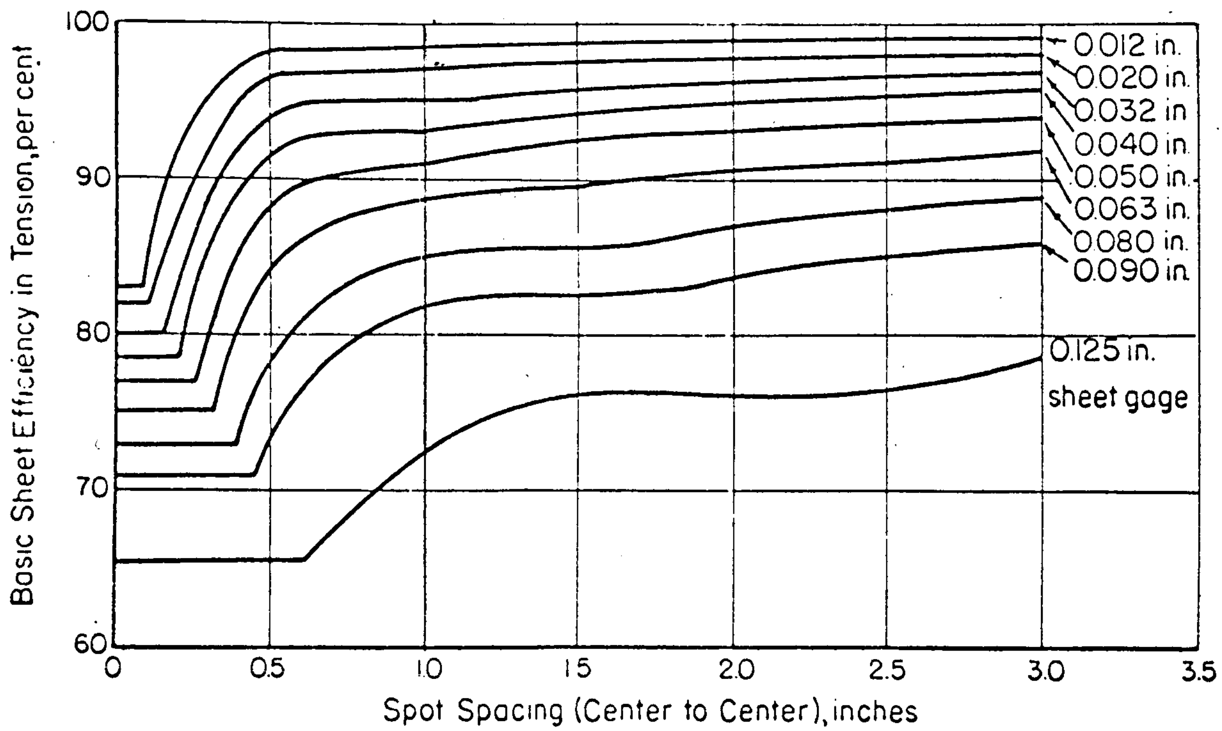


FIG. 12.6 EFFICIENCY OF THE PARENT METAL IN TENSION FOR SPOT-WELDED TYPE 301 SHEET IN 1/2 HARD CONDITION (Ref. 12.13)

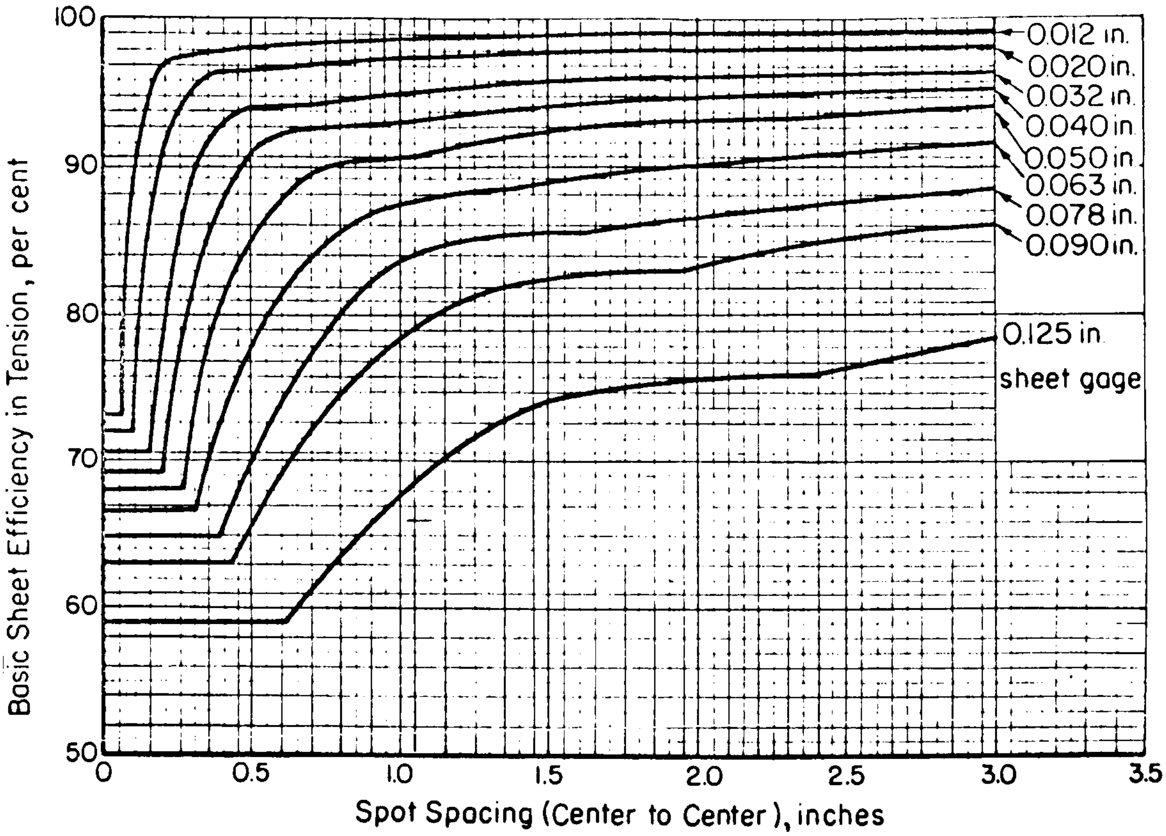


FIG. 12.7 EFFICIENCY OF THE PARENT METAL IN TENSION FOR SPOT-WELDED TYPE 301 SHEET IN FULL HARD CONDITION (Ref. 12.13)

CHAPTER 12 - REFERENCES

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